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Preliminary Geotechnical, Hydrological and Environmental Services, Retorted Shale Disposal Area,

Cathedral Bluffs Shale Oil Project,
C-b Tract, Rio Blanco County, Colorado

Contract CB-13-83

Copy for
Ed Baker

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Preliminary Geotechnical, Hydrological And Environmental Services

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Retorted Shale Disposal Area
Cathedral Bluffs Shale Oil Project
C-b Tract, Rio Blanco County, Colorado

Prepared For

Cathedral Bluffs Shale
Oil Company
Grand Junction, Colorado

May 1983

Contract No. CB-13-83

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Woodward-Clyde Consultants

Consulting Engineers, Geologists and Environmental Scientists
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Job No. 21120-19605

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May 10, 1983

Cathedral Bluffs Shale Oil Company
P.O. Box 2687
Grand Junction, CO 81502

Attention: Mr. Eric S. Watson
Project Manager

Re: Preliminary Geotechnical, Hydrological and Environmental Services, Retorted Shale Disposal Area, Cathedral Bluffs Shale Oil Project, C-b Tract, Rio Blanco County, Colorado, Contract No. CB-13-83. Job No. 21120-19605

Gentlemen:

We have completed the geotechnical, hydrological and environmental services discussed in our March 3, 1983 letter for the above-referenced project. Data gathered during our studies and our preliminary opinions and recommendations concerning disposal of retorted shale from your planned above-ground shale oil retort are presented in the following report.

We believe the preliminary disposal plan discussed in the report should provide the basis for the design of an environmentally and economically sound retorted shale disposal facility. Major elements of the plan to dispose of the retorted shale in Cottonwood and Sorghum Gulches include (1) provisions to place the majority of the retorted shale without compaction, (2) a compacted retorted shale blanket over and beneath the uncompacted material, (3) pile slopes formulated to provide for pile stability, reclamation and runoff control, (4) a pile configuration that limits the height of the pile above existing ridge lines, (5) diversion channels to route Sorghum Gulch streamflows originating upstream of the pile (off the C-b Tract) to the easternmost fork of Sorghum Gulch, which is not used for retorted shale disposal, and (6) a pile reclamation procedure that uses retorted shale overlain by the topsoil available at the site. The pile construction sequence discussed in the report should also result in a relatively uniform, low rate of retorted shale compaction for the blanket beneath and over the pile for the life of the project. Therefore, equipment and manpower needs for retorted shale deposition, for both the compacted and uncompacted zones of the pile, should also remain relatively fixed over the project life.

The pile surface configuration and reclamation zone are formulated to reduce surface water runoff and to promote vegetative growth. The suggested pile construction sequence would allow much of the pile surface to be reclaimed during ongoing retorted shale deposition, and well before retiring the pile. However, during construction, runoff control from "active" unreclaimed portions of the pile would be needed. Preliminary design recommendations concerning during-construction runoff control are provided in the report, as are during-construction and post-reclamation water balances.

If you have questions, please call.

Yours truly,

Frank J. Holliday

Frank J. Holliday
Vice President

WLZ:gg

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STATE OF COLORADO

Preliminary Geotechnical, Hydrological And Environmental Services

Retorted Shale Disposal Area
Cathedral Bluffs Shale Oil Project
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PRELIMINARY GEOTECHNICAL, HYDROLOGICAL AND ENVIRONMENTAL SERVICES RETORTED SHALE DISPOSAL AREA CATHEDRAL BLUFFS SHALE OIL PROJECT C-b TRACT, RIO BLANCO COUNTY, COLORADO

INTRODUCTION

Oil shale from the Cathedral Bluffs Shale Oil Company room and pillar mine and to develop the modified in-situ retorts at the C-b Tract, Rio Blanco County, Colorado, will be retorted and disposed of above-ground.

This report presents the results of the study performed to develop preliminary recommendations concerning (a) the impact of site subsurface and hydrologic regimes on planned retorted shale disposal, and (b) a proposed retorted shale disposal method and pile configuration that considers site subsurface conditions, ground and surface water hydrology, and reclamation details. Data from the study are summarized on Figures 1 through 26, Tables 1 through 23 and in Appendix A. Information regarding the physical/chemical properties of retorted shale from the Union Oil Company of California's (UOC's) Unishale B process was obtained from the UOC Mined Land Reclamation Board Permit Application dated December 9, 1982.

PROJECT DESCRIPTION

Oil shale removed from the Cathedral Bluffs Shale Oil Company's room and pillar mine and to develop the planned underground modified in-situ (MIS) retorts will be retorted above-ground using a Union B process retort. The retorted shale from that above-ground facility, and a small amount of non-retorted shale fines (minus 1/8-inch material) mixed with the retorted shale, will be disposed of east of the plant site in Cottonwood and Sorghum Gulches. About 171,700,000 tons dry weight of material will result from the retorting operation during the planned 45-year project life. The retorted shale material will be conditioned and cooled in

a wetter drum prior to its deposition. Conveyor systems feeding self-propelled stackers will be used for most of the material. A stockpile bench at the wetter facility is planned as an area to handle retorted shale production surges.

SITE CONDITIONS

The proposed retorted shale disposal area is currently located entirely within the property boundaries of the C-b Tract and east of the Cathedral Bluffs Shale Oil Company plant site. The disposal area will overlie some of the underground room and pillar mine workings. Cathedral Bluffs Shale Oil Company indicates the mine is designed as a non-subsiding mine and will, therefore, not impact disposal area designs. Two gulches, each containing northward-flowing, intermittent streams that connect with the Piceance Creek valley about a mile north of the site, cross the site. The easternmost of the gulches, called Sorghum Gulch, has two forks that join near the northern property line. The head of Cottonwood Gulch, the westernmost of the gulches, is located within the C-b Tract boundaries. However, the westernmost fork of Sorghum Gulch originates about 1 1/2 miles south of the southern property boundary.

The site slopes gently to the north, dropping about 650 feet across its about 2 1/2-mile length. Topographic relief within the site from ridges to gulch bottoms is up to about 300 feet. Bedrock outcrops locally along the walls of these gulches, particularly near their north ends, forming narrow-bottomed, steep-walled (sometimes overhanging) sections. These sections have between about 10 to 50 feet wide bottoms and near-vertical walls sometimes extending up to about 30 feet above the adjacent streambed. They are generally located along the northern reaches of the gulches north of about Coordinate Line N 183,000. However, they are locally found south of that line in Sorghum Gulch. We estimate those steep-walled sections south of about Coordinate Line N 183,000 randomly involve about a third of the

length of Sorghum Gulch. They are generally shallower than the sections near the north ends of the gulches.

Vegetation, consisting of juniper, pinyon, sagebrush and other plant species typical of the Piceance Creek area covers the site surface. Much of the area had been chained by the Bureau of Land Management in 1967 as part of a range improvement program. Many dead trees from that chaining process are scattered across the site.

GEOLOGY

The C-b Tract is located in the northeastern section of the Piceance Creek basin, east of the basin axis. The Piceance Creek basin is a large northwest-trending structural downwarp about 130 miles long and 70 miles wide. The project facilities are south of Piceance Creek, a northwest-flowing stream that drains this section of the basin and flows into the White River to the north. The Uinta Formation is the near-surface bedrock. The beds of that formation in the project area are near horizontal, dipping very gently to the northwest at angles of up to about 5 degrees.

The Uinta Formation bedrock at the site consists mainly of sandstone with subordinate siltstones and marlstones. The beds of the formation crop out in prominent cliffs and steep slopes along Cottonwood and Sorghum Gulches. The sandstones range from thin bedded with well-defined bedding to massive with poorly-defined bedding. The beds, as observed, ranged from being closely jointed and fractured to very widely jointed. The sandstones are generally medium to fine grained and are moderately cemented.

The bedrock appears to be mantled by a few inches to a few feet of slopewash and residual soils in the upland areas between the south to north-trending gulches across the site. From 6 inches to 9 1/2 feet of silty and clayey to very silty and very clayey sands and sandy clays were found over sandstone bedrock in test pits we excavated in those areas.

Uinta Formation bedrock outcrops along the floors of the gulches and is locally covered with alluvial (stream deposited) soils. The depths of these soils appear to be thin along most of the southern reaches of the gulches and to thicken near the northern property boundary. From 4 to 13 feet of such alluvial soils, consisting of gravelly clayey sands, were exposed in test pits we excavated along the bottom of Sorghum Gulch. The test pit excavated at the southern end of the gulch (TP-3) showed 4 feet of such soils over Uinta Formation sandstone bedrock. However, the two test pits at the bottom of the gulch near the northern property boundary (TP-7 and TP-8) were excavated to depths of 12 to 13 feet without reaching bedrock. Based on correlations of information concerning the depths of alluvial soils indicated by the test pits excavated for this study with data provided by Cathedral Bluffs Oil Shale Company concerning the depths to bedrock in wells located in the alluvium at the mouth of Cottonwood and Sorghum Gulches, about 1 1/2 miles north of the property line, the alluvium thickness could be as thin as 15 feet at the northern property boundary.

Our interpretation of the disposal area surficial geology is shown on Figure 1, as are the locations of the test pits excavated for this study. Summary logs of the test pits are provided on Figure 2. Laboratory test results from selected samples from the test pits are provided in Appendix A.

RETORTED SHALE DISPOSAL

General

This disposal plan for retorted shale addresses a variety of geotechnical, hydrological and environmental considerations. We believe the preliminary disposal plan discussed in this report provides the basis for the design of an environmentally and economically sound retorted shale disposal facility.

Major elements of the preliminary plan include (1) retorted shale disposal in Cottonwood Gulch and the western fork of Sorghum Gulch, (2) diversion

channels to route water flowing down the western fork of Sorghum Gulch upstream of the disposal area to the eastern fork of Sorghum Gulch, prior to its reaching the retorted shale disposal pile, (3) a compacted retorted shale blanket over and beneath the pile, and (4) pile slopes formulated to provide for pile stability, reclamation and runoff control from the pile. The pile top "stair-steps" down from south to north, generally following the slope of the existing ground surface. The pile top would be a maximum of about 100 feet above the adjacent ridge lines and generally no more than about 50 feet above the ridges. The compacted retorted shale blanket encapsulating the pile reduces the rate of moisture infiltration into or out of the pile, thus allowing for the majority of the retorted shale to be placed without engineered compaction. It also enhances the stability of the exterior pile slopes. The preliminary plan also provides for a relatively uniform low rate of compacted retorted shale to be placed over the life of the project. Therefore, equipment and manpower needs pertaining to the compaction would remain uniform. Except for short periods of time when starting disposal in Cottonwood and Sorghum Gulches, periodically expanding and/or reducing the work force needed to place the compacted zones would not be needed.

Plan views of the retorted shale disposal pile at various stages during its development and section views corresponding thereto are shown on Figures 3 through 14 and are discussed below. As shown on the figures, four zones or uses are planned for the retorted shale. Zone I is compacted material used to encapsulate the pile. The uncompacted retorted shale is designated as Zone II material. Zone III material is retorted shale that would receive light compaction, as needed, to facilitate adjacent Zone I construction. A 5-foot thickness of uncompacted retorted shale would also be used in the reclamation zone atop the pile. That retorted shale would overlie the Zone I blanket atop the pile, and would in turn be covered with topsoil. Estimated quantities of the retorted shale zones within the planned disposal area, consistent with the preliminary disposal plan discussed below, are shown on Table 1.

Disposal Plan

Many possible combinations involving varying disposal rates, equipment, areas being used for disposal at any given time, retorted shale lift thicknesses, compaction methods and other related items, could be developed and incorporated into disposal plans. We have assumed in our analysis that the retort plant will operate with an efficiency stream factor of about 0.3 over the first 6 months of operation, increasing to 0.75 over the next year, and reaching a steady state stream factor of 0.92 after 1.5 years, continuing through the planned project life of 45 years. The preliminary plan discussed below assumes: (1) 171,700,000 tons of retorted shale will be delivered to the disposal site over its 45 years of operation (corresponding to an average disposal rate of about 3,820,000 tons per year; (2) disposal will begin and continue in Cottonwood Gulch until that gulch is filled, at which time disposal will begin in Sorghum Gulch; (3) disposal in Cottonwood Gulch will begin at its upstream end, and near the south property line in Sorghum Gulch, and will proceed uniformly down each gulch to the north with the advancing face of the pile placed to fill each gulch from their east to west sides; (4) Zone II materials will be placed using conveyors and stackers; and (5) the average maximum height of the downstream face of any individual lift of Zone II material will be 100 feet or less.

Retorted shale deposition will begin at the south end of Cottonwood Gulch, at the ridge line separating the north-sloping and south-sloping ground, and proceed to the north. By doing so, potential surface water flow onto the pile from Cottonwood Gulch drainage areas uphill of the pile will be eliminated, and such runoff from as yet "undisturbed" areas downslope of the pile would follow existing natural drainage patterns until such time as those areas needed to be incorporated into the pile. Combined with the pile slope configuration and reclamation method discussed below, this will reduce the area from which surface runoff will need to be handled during pile construction to that from "active" unreclaimed areas of the

pile where retorted shale was currently being placed. Runoff from disturbed areas just downstream of the disposal pile will be collected in temporary ponds, as discussed below under "HYDROLOGIC ASPECTS."

A compacted Zone I lining underlying subsequently placed Zone II material will be the first retorted shale placed at the head of Cottonwood Gulch. This will involve staged clearing and grubbing of vegetation and stripping and stockpiling topsoil from the initial area to be lined before compacting the 5-foot thick lining over the stripped area. We estimate the southernmost 800 feet of Cottonwood Gulch would be so lined in about 3 months assuming the full retort production of retorted shale was used for that period. After that 3-month period, most of the retorted shale will be placed as Zone II (uncompacted) material. However, clearing, stripping and lining Cottonwood Gulch downstream of the advancing Zone II pile face will continue. The 5-foot thick layer of Zone I material over the top of the pile completed to grade and the overlying reclamation zone will also be placed in conjunction with Zone II placement.

The Zone II material will be placed over completed sections of the Zone I blanket using conveyor-fed equipment. The face of the pile will be incrementally and continuously extended to the north by the equipment traversing east and west across the gulch, just south of and atop the advancing face, depositing additional material on that face. When the average maximum height of that face reached about 100 feet, the equipment will be moved down to the toe of the face to begin a new similar lift, or if the top of the lift they were working on was not to final pile grade, could move to the south end of that lift to start the next overlying lift.

The advancing face of the Zone II section of the disposal pile will be constructed by dumping retorted shale from atop the particular lift of the pile being constructed at any given time. We assumed the maximum average height of the lifts would be about 100 feet. However, thicker, and/or thinner, lifts could be used, depending on the size and weight of the

placement equipment, the moisture content of the retorted shale, and the proximity of the equipment to the pile face. We believe lifts of up to about 150 feet are possible. However, the relationships between the stability of the Zone II slopes and placement equipment requires further study prior to final equipment selection. For your preliminary cost estimates, we suggest assuming (1) average maximum downstream Zone II slope heights of 100 feet, (2) placement equipment would operate no closer than about 25 feet to the crest of Zone II slopes, and (3) the dumped Zone II materials would stand on angles of repose of about 1 1/3:1 (horizontal:vertical) or flatter.

Incremental advancement of the pile down Cottonwood Gulch should be planned so that (1) as much of the upstream portion of the pile as possible is completed to grade prior to extending the pile further downstream, (2) sufficient clearing, stripping and Zone I liner construction downstream of the advancing Zone II pile face is performed, and at a relatively uniform rate, to provide for unrestricted Zone II construction, and (3) the pile raised to planned grades is covered with the Zone I blanket and reclamation zone as soon after completion of the pile as is practical. Completing as much of the upstream portions of the pile as is practical prior to extending it downstream reduces the area from which surface water drainage needs to be contained using ditches and temporary ponds at the downstream edges of pile construction. Expeditious completion of the Zone I blanket and reclamation zone atop the pile also enhances runoff control as the pile slopes and reclamation zone are designed to accommodate precipitation falling on the reclaimed portions of the pile.

Based on the assumptions concerning the method of pile construction discussed above, and rates of placement of the various zones of retorted shale discussed below under "Disposal Rates," the Zone I blanket placed over the ground surface in advance of the advancing face of the Zone II portion of the pile would extend an average of about 500 feet, and a maximum distance of about 1500 feet, downstream from the toe of the Zone II material. In addition, the Zone I blanket and the overlying reclamation

zone atop the pile could be maintained almost directly at the downstream edge of the portion of the pile completed to grade. The combined area of the Zone II material exposed at the downstream face of the pile as it is being constructed and of the Zone I lining material placed over the natural ground downstream of that Zone II material would amount to about a maximum of about 200 acres at any given time.

Topsoil stripped from the ground surface in advance of Zone I lining placement will be stockpiled for future use, or hauled directly to sections of the pile completed to grade and placed in the reclamation zone. However, some stockpiling will be necessary. For example, the topsoil removed from the extreme upstream area of Cottonwood Gulch to prepare it for Zone I placement at the beginning of the project will need to be stored as there will be no completed disposal pile area available for its use at that time. A similar situation could occur when starting the disposal pile in Sorghum Gulch. In addition, there will be a period of time during disposal in both Cottonwood and Sorghum Gulches when the entire bottom area of the disposal pile has been lined with Zone I material, thus all the topsoil removed, but when the top of the pile has not been completed to grade. Topsoil will need to be stored for use on the top of those sections of the pile as they are completed.

Prior to completion of the Zone I blanket over the ground surface beneath the planned pile footprint, topsoil would be temporarily stockpiled within the planned disposal area. Those piles would be used prior to retorted shale deposition reaching their locations. Stockpiles could also be placed atop the pile, or adjacent to and outside the eventual pile locations. Stockpiling within the disposal area, including atop completed portions of the pile, would reduce disturbed areas outside of the pile boundaries. Disturbed areas outside the pile boundaries, as well as the pile itself, would eventually have to be reclaimed. Topsoil stockpiles atop the pile could, we believe, be most effectively used if they were located in areas where the pile top had reached planned grades, but where reclamation had

not been started. Such locations would result in the piles not having to be relocated prior to the topsoil use in reclamation zones, and would reduce the effect of construction equipment hauling the topsoil on reclaimed areas where topsoil and seeding had been completed. However, the locations should be planned near the area where the topsoil will be used, and sufficient material should be placed in each pile to cover the area planned for its use. Potential topsoil stockpile locations, which are typical of many that could be chosen, are shown on Figures 3 through 7.

As the disposal pile is completed to the north, it will begin to overlie the narrow, steep-walled sections of Cottonwood Gulch. Those steep-walled sections generally appear to be located north of about Coordinate Line N 183,000, as discussed above under "SITE CONDITIONS." Compacting Zone I materials in the steep, narrow sections of the gulches, particularly against the steep, sometimes overhanging walls, would be difficult. We believe it would be more practical to fill the lower portions of those sections with rockfill that could be dozed into place and compacted with heavy construction equipment. When the top of that rockfill reached more gentle terrain where Zone I hauling and compaction equipment could operate, the Zone I lining could be placed. As shown on Figure 15, we recommend the rockfill consist of low-grade oil shale or Uinta Formation rock with a maximum size of 36 inches that would be placed in maximum 3-foot thick loose lifts and be compacted with heavy construction equipment. Such rock could come from the mine and/or the Sorghum Gulch water diversion channels. We also recommend the Zone I blankets both beneath and over the Zone II material over such rockfill sections be 10 feet thick. The thicker blankets reduce chances of their cracking should settlement occur in the rockfill or the underlying alluvial soils. The thicker depths of alluvial soils at the gulch bottoms generally appear to coincide with the locations of the steep, narrow sections of the gulches.

Based on the construction sequence of the pile, the Zone I blanket over the ground surface and beneath the pile will reach the planned downstream toe

of the Cottonwood Gulch portion of the pile about 7 years after beginning retorted shale placement. The lift of Zone II material furthest downstream will be about 1000 feet upstream of the downstream toe at that time. When the Zone I blanket reaches the downstream toe area, construction of a retorted shale embankment to eventually be incorporated into the retorted shale disposal pile to form the downstream face of the pile will begin. The embankment will be raised at a rate to place its top at an elevation equal to the elevation of the advancing lift before that lift reaches the downstream toe embankment. The embankment will have a compacted Zone I lining, overlain by a reclamation zone, as shown on Figure 16. Some Zone III material, which is retorted shale compacted with hauling and/or compaction equipment only as needed to facilitate the compaction of the adjacent Zone I material, will be incorporated into the embankment, also as shown on Figure 16.

The slope at the downstream toe of the Cottonwood Gulch portion of the pile, those slope faces between benches of the stair-stepping pile top, as well as the slope faces to be constructed for the Sorghum Gulch pile, are all planned at 4:1 overall slope angles and incorporate benches evenly spaced up the slope. The slope angle was selected to (1) provide for slope stability and (2) facilitate reclamation of the slopes. The benches also assist in collecting and evaporating surface water runoff from the pile top prior to the establishment of the vegetation on the reclamation zone. Preliminary slope and bench details are shown on Figure 16.

Using the procedures and deposition rates discussed above, it appears the Cottonwood Gulch portion of the pile will be completed about 12 years after starting the retort. A plan view of the pile and a section through the pile at that time are shown on Figures 4 and 10, respectively. A plan view of the pile and a section showing the estimated pile configuration 5 years after starting the retort is shown on Figures 3 and 9, respectively.

Deposition of retorted shale in Sorghum Gulch will begin when the Cottonwood Gulch section of the pile is completed. However, some work will be needed to prepare the upstream end of Sorghum Gulch within the C-b Tract property line for retorted shale deposition prior to that time. Excavation of channels to divert streamflows from the west to the east fork of Sorghum Gulch, as shown on Figures 4 through 8 would be completed prior to any work within the Sorghum Gulch retorted shale disposal area. The channels, that protect the downstream Sorghum Gulch disposal area from runoff down Sorghum Gulch, could be excavated anytime prior to the beginning of retorted shale deposition in Sorghum Gulch.

Before placement of Zone II material could be started in Sorghum Gulch, an initial upstream area would need to be lined with Zone I material, as previously discussed for the initial construction at the head of Cottonwood Gulch. In addition, since the pile in Sorghum Gulch will not begin at the head of the gulch, the upstream end of the pile will eventually extend about 100 feet above the stream channel. That pile height assists in directing streamflows into the diversion channels and provides additional retorted shale storage. Raising the upstream end of the pile will also be in stages, involving the construction of an embankment similar to the one at the downstream toe of the Cottonwood Gulch pile. The embankment includes a reclamation zone, a Zone I blanket, and an adjacent Zone III area, as needed. The initial embankment height will be about 50 feet. Vegetation removal, topsoil stripping, Zone I liner and embankment construction in Sorghum Gulch should begin about 6 months prior to completion of the Cottonwood Gulch portion of the pile to provide for uninterrupted retorted shale deposition.

The east side of the Cottonwood Gulch portion of the pile will eventually be incorporated within the pile as Sorghum Gulch is filled. However, until that time, some of the east slopes of the Cottonwood Gulch pile will be exposed, as shown on Figures 3 through 7. The slopes will be exposed for between about 5 to 40 years, the time it takes the disposal pile in Sorghum

Gulch to be placed far enough to the north to cover them. We recommend your preliminary designs and cost estimates assume that those slopes will have 4:1 angles and will include benches, similar to completed pile end slope showns on Figure 16. The benches reduce chances of precipitation running off of those temporary slopes prior to their being covered with retored shale placed as part of the Sorghum Gulch phase of pile construction, particularly if the slopes include a Zone I blanket and are reclaimed. However, subsequent studies may show those slopes can be constructed of lightly compacted unreclaimed retorted shale, similar to Zone III material.

Except for the upstream embankment, the Sorghum Gulch pile will be constructed using procedures similar to those for Cottonwood Gulch retorted shale deposition. Using those procedures, the advancing face of the pile will reach the planned downstream toe about 40 years after retorting begins. The construction of the downstream face of the pile will begin at that time so the pile can be completed by the planned 45-year project shutdown date. Typical sections through the Sorghum Gulch portion of the pile at times of 20, 30, 40 and 45 years after starting the retort are shown on Figures 11 through 14. Typical pile plans 20, 30 and 40 years after the beginning of the project and upon pile completion (45 years) are shown on Figures 5 through 8, respectively.

Disposal Rates

About 171,700,000 tons of retorted shale will be produced during the 45 years of retort operation, as discussed above under "PROJECT DESCRIPTION." We understand the retort plant will not reach steady state production of about 3,860,000 tons of retorted shale per year until after 1.5 years of operation. Prior to that time, the plant will produce at efficiency rates of 0.30 for the first 6 months, and 0.75 for the next 12 months. This results in average annual retorted shale production rates of about 3,820,000 tons per year. Most of the retorted shale within the disposal pile, will be uncompacted (Zone II and reclamation zone) or

lightly compacted (Zone III). The disposal plan discussed above includes a compacted Zone I blanket encapsulating the pile that is about 13 percent (by weight) of the total retorted shale. Estimated quantities of the various pile zones are shown on Table 1. A timetable showing the estimated amounts of the various uses of retorted shale within the disposal area, and total retorted shale quantities throughout the project life is provided on Figure 17.

Retorted shale placed within Zone I areas of the disposal pile will be the only material that will need to be spread in thin lifts, conditioned to the optimum moisture content for compaction and compacted. Estimated average Zone I deposition rates, consistent with the preliminary disposal method developed for this study are shown on Figure 18 and are discussed below for use in estimating equipment and manpower needs and associated costs.

About 3,500 tons per day (about 2600 yd^3 per day) of retorted shale will be compacted into the Zone I lining at the head of Cottonwood Gulch during the first about 3 months of plant operation to prepare that area for subsequent and ongoing retorted shale deposition. Those quantities assume an initial plant production rate of 620,000 tons of retorted shale for the first half year, a compacted retorted shale dry density of 99 pcf and 365 days per year of plant operation. We estimate a total of about 820,000 tons per year (about 1650 yd^3 per day) of retorted shale would need to be compacted into the Zone I blankets atop and beneath the pile over the next 5 years to maintain Zone II placement and to expedite pile reclamation. After about 5 years of deposition, the Zone I blanket atop the completed portions of the pile reaches the crest of the slope down into the advancing pile face, as shown on Figure 9. At that time, the Zone I blanket over the pile will be placed at a rate of about 100,000 tons per year (about 200 yd^3 per day). The placement rate for the Zone I blanket beneath the pile remains at about 550,000 tons per year (about 1100 yd^3 per day) until about the end of year 7, when that blanket reaches the planned downstream toe of the Cottonwood Gulch pile. No additional lining material will be placed at the

ground surface until about year 11.5 when lining of Sorghum Gulch starts. However, Zone I material will continue to be placed atop completed portions of the Cottonwood Gulch pile at a rate varying between about 75,000 and 280,000 tons per year (150 to 575 yd^3 per day), and in the downstream slope of the Cottonwood Gulch pile at a rate of about 130,000 tons per year (about 265 yd^3 per day), resulting in about 410,000 tons per year (about 840 yd^3 per day) of Zone I placement between about years 7 through 10, and about 205,000 tons per year (about 420 yd^3 per day) between about years 10 and 11.5 as shown on Figure 18.

The upstream area of Sorghum Gulch will begin to be prepared for retorted shale placement about 11.5 years after starting the retort, and Cottonwood Gulch disposal will be completed over the next 6 months. Zone I compaction rates of about 1,900,000 tons per year (about 3900 yd^3 per day) will be needed for Zone I blanket atop the Cottonwood Gulch pile, the blanket beneath the upstream end of the Sorghum Gulch pile, and the upstream face of the Sorghum Gulch pile during those 6 months. After that intense period of Zone I construction, placement rates of between about 215,000 to 430,000 tons per year (440 to 880 yd^3 per day) will be needed for Zone I linings beneath the pile until about year 40, when the Sorghum Gulch bottom lining is completed. Zone I placement rates atop the pile will be about 60,000 to 270,000 tons per year (125 to 550 yd^3 per day), for a total Zone I placement rate between about 300,000 to about 660,000 tons per year (about 615 to 1350 yd^3 per day) during that period. However, as shown on Figure 18, the higher rate of about 660,000 tons per year will only be over an about 5-year period when the top lining is catching up to the Zone II face. About 500,000 tons of the retorted shale per year (about 1000 yd^3 per day) will be required for the downstream pile slope and atop the pile for the last 5 years of the project between years 40 and 45.

To maintain the disposal plan the yearly Zone I material placement rate varys between about 215,000 and 820,000 tons per year, corresponding to daily rates of about 440 to about 1700 yd^3 per day. Except for the

short 3-month period at the beginning of the project, and the 6-month period when the pile in Cottonwood Gulch is being completed and the upstream end of Sorghum Gulch is being prepared, less than 1700 yd^3 per day of the retorted shale would need to be spread, mixed and compacted as Zone I material. Even the maximum 1700 yd^3 per day placement rate is well within the capabilities of large conventional compaction equipment on the market today. At the start-up of the Cottonwood Gulch and Sorghum Gulch pile segments, up to 2600 to 3900 yd^3 of Zone I material needs to be placed daily. Large volumes of clearing and grubbing, and topsoil stripping will also be needed at those times. Considering the short periods of time involved, it may be more cost effective to temporarily subcontract earthwork contractors to perform that start-up work.

Compaction Methods

Most of the retorted shale will be transported to the disposal areas using conveyors feeding placement equipment, and all of the Zone II materials will be dumped into thick lifts. Zone II lift thicknesses could vary and will depend, in part, on the area being filled, the type of equipment being used to place the lift, and retorted shale properties. The only compaction to be applied to most Zone II materials would be from equipment hauling and spreading the retorted shale. However, some surface rolling, probably with wheeled hauling equipment, dozers and/or compactors, may be needed on the surface of the thick lifts to help stabilize them for subsequent equipment movement. Depending on the method used to place the Zone II retorted shale, and the depth of overlying retorted shale, we estimate their dry density will vary between 70 and 85 pcf. At those densities, the retorted shale could hold about 16 to 20 percent moisture, by weight, would have angles of internal friction of between 35 and 38 degrees, and cohesion values of up to about 200 psf.

We believe your ongoing designs and cost estimates should assume Zone I materials will be spread in about 8-inch thick horizontal loose lifts

using scrapers and/or trucks. Bladed compaction equipment and/or graders should be used to level the lifts and to mix moisture with them. Depending upon the initial moisture content of the retorted shale used for Zone I materials, discs may also be needed to facilitate moisture mixing. After moistening the loose lifts to near the optimum moisture content for compaction, they would be compacted to high density with heavy compaction equipment. For your preliminary designs and cost estimates, we suggest you assume the Zone I material will be compacted to 100 percent maximum density (ASTM D 1557). However, further studies of relationships between the degree of compaction and the permeability of the compacted Cathedral Bluffs retorted shale may indicate lower compactive efforts could be used. We believe optimum moisture and density conditions for the retorted shale at 100 percent ASTM D 1557 compactive effort should be about 21 percent and 99 pcf, respectively. We estimate compacted Zone I material would have an angle of internal friction of about 39 degrees.

We suggest you assume for estimating purposes Zone I compaction densities can be achieved by 6 to 8 passes of conventional heavy compaction equipment, consisting of self-propelled sheepsfoot-type rollers, preferably equipped with blades for leveling the fills. Self-propelled, non-vibrating sheepsfoot rollers, such as a Caterpillar Model 825B, or equivalent, or heavy self-propelled vibrating rollers, such as a RayGo Rascal 420C or 450A, or equivalent, are examples of such equipment. The mobility of the compactors, thus their ability to travel quickly between different work areas and up and down sloping ramps between those areas, should be considered.

Some retorted shale placed directly adjacent to and concurrent with the Zone I materials in pile slopes, may require some compaction to facilitate Zone I compaction. This Zone III material will temporarily buttress the adjacent Zone I material until the Zone II retorted shale within the pile reaches the level of the pile face. Moisture would not need to be added to Zone III materials and that they could be compacted, as needed, by

selective routing of hauling equipment, or by compactors placing the Zone I materials. Zone III material lift thickness could be up to 5 feet.

The retorted shale in the reclamation zone over the completed pile could be spread in single lifts. The only compaction that the lifts would receive would be from hauling equipment traveling over them.

Prior to placing Zone I materials, vegetation covering the existing ground surface will be removed, as will topsoil. The bedrock is shallow over most of the disposal site. Therefore, except for soft areas that may be caused by precipitation between the time when the areas are stripped and the linings are placed, we do not believe the ground surface will need to be compacted or otherwise treated for retorted shale deposition. Soft or wet areas that will not support construction equipment will have to be removed or compacted, prior to compacting retorted shale over them.

Water Requirements

About 16 percent moisture (Stearns-Roger Engineering Consultants, 1983) will be added at the wetter facility to the dry retorted shale from the retorting process. Some of that moisture will be lost to evaporation as the added water cools the hot retorted shale. A moisture content of 14 percent by weight is anticipated for the retorted shale delivered to the disposal area.

We estimate about 280 gpm of water would be needed over the 45-year life of the project to moisten the 171,700,000 tons of retorted shale to be produced from a dry condition to a moisture content of 16 percent (in the wetter facility). Of that moisture, about 35 gpm will be lost as evaporation as the retorted shale moisture content drops from 16 to 14 percent. An overall average of about 16 gpm would then be needed to raise the moisture content of the estimated 23,030,000 tons of retorted shale to be used as Zone I material from 14 percent to 21 percent, the optimum moisture

content for compaction. Average daily water needs to raise the moisture content of the Zone I materials from 14 percent to 21 percent, are for deposition rates shown on Figure 18. The above-discussed estimates assume water would be added to the retorted shale 365 days per year, 24 hours per day for 45 years. The moisture contents are by weight. A summary of estimated water requirements for construction and irrigation of the retorted shale disposal pile is given on Figure 25.

Water would also be needed to establish plant growth atop the reclamation zone. Details concerning the areas available for reclamation throughout the project life and types of plants that could be used, are discussed below under "RECLAMATION," and estimated precipitation under "HYDROLOGIC ASPECTS." An additional 8 inches of moisture per acre in excess of the average yearly effective moisture available from precipitation would be added to the reclaimed areas for a 1-year period to help establish growth. It is planned that the plant on the pile would be seeded in the fall and first irrigated the following spring for 6 months (see Table 22).

Settlement

Downward movement or settlement of the surface of the retorted shale pile will be a function of the properties of the retorted shale within the pile, the underlying natural soils and bedrock, and time. Since shallow depth bedrock underlies most of the disposal area, pile settlement due to consolidation of the underlying materials should be small. Some additional pile settlement could occur along sections of the pile that overlie deeper alluvial soils at the bottom of Cottonwood and Sorghum Gulches, or the steep sections that will be backfilled with rockfill prior to construction. The small potential for pile settlement from consolidation of the underlying materials, permits using a 5-foot thick compacted shale lining (Zone I) to encapsulate most of the pile. In areas where potential settlement is greater, such as over the rockfill sections of Cottonwood and

Sorghum Gulches, and as shown on Figures 4 through 8, lining thicknesses of 10 feet are planned.

Pile settlement due to the retorted shale within the pile will depend upon the gradation of the material, strength of individual particles and groups of particles, pile height, moisture conditions, placement methods and resulting initial placement densities of the retorted shale. Most Zone II settlement will occur as the pile is being constructed prior to Zone I placement as the granular retorted shale adjusts under the increasing weight of the overlying retorted shale. The total downward movement of the top of the pile between its completion and the completion of pile settlement will only be a fraction of that total settlement. We estimate post-reclamation pile settlement could be of the order of 2 to 3 percent of the depth of the retorted shale within the pile at any given location.

HYDROLOGIC ASPECTS

Retorted Shale Disposal Pile Water Balance

The water balance of the retorted shale disposal pile located in Cottonwood and Sorghum Gulches was computed under three sets of conditions: (1) during-construction, (2) supplemental irrigation during reclamation, and (3) post-reclamation. Analyses for the retorted shale disposal pile consisted of a preliminary water balance using a modeling technique similar to that used by Wymore (1979) for UOC's Phase I permit (UOC, 1979), and an update of the water balance done for UOC's Phase II permit (UOC, 1982).

The water balance approach used a simplified unsaturated flow model along with monthly precipitation and evapotranspiration data as model inputs. Evaluations were conducted for the 1951-through-1980 period, except when data were limiting, in which case a shorter period was used. This 30-year period is representative of climatological conditions of the study site and includes several wet and dry years, including the driest year of record

(1977). This period serves as the basis for the analyses described below. Individual years are noted sequentially from 1 to 30 in the study to reflect this period used in the analysis.

The potential for water movement into the retorted shale disposal pile during construction and after reclamation was investigated using this unsaturated flow model. The model was used to simulate the movement of water into the surface materials by precipitation and out of the surface materials by evapotranspiration on a daily and monthly basis, and the movement of water within the upper 6 feet of the disposal pile materials. The data to run the model include soil properties and initial saturation conditions, and precipitation and evapotranspiration rates. Model outputs are fluxes of water into and out of the upper 6 feet of material by the processes of evaporation, transpiration and infiltration, and changes in percent water saturation at 1-foot intervals within the upper 6 feet of material. For the during-construction case, it was assumed that water infiltrating deeper than 0.5 foot could not be removed by evaporation. The during-construction model assumed the upper 6 feet of material consisted entirely of Zone II retorted shale. For the post-reclamation case, it was assumed that water infiltrating deeper than 6 feet could not be removed by evapotranspiration from the soil layers, and this water represents vertical water movement into the retorted shale disposal pile. The post-reclamation model assumed the upper 6 feet of the pile consisted of 1 foot of topsoil over 5 feet of uncompacted retorted shale (the reclamation zone).

Simulation of the during-construction and post-reclamation water balances of the retorted shale disposal pile used two periods of record. The during-construction water balance was done for the 1951-through-1970 period which was limited by data availability on wind speed and relative humidity at the National Weather Service Grand Junction Station. The post-construction water balance used the entire 1951-through-1980 period. All water balance estimates were made using monthly increments.

Monthly precipitation (Table 2) was estimated at the site, based on correlating monthly site precipitation provided by Cathedral Bluffs with concurrent monthly precipitation at the National Weather Service Little Hills Station located about 12 miles north of the site. Correlating 81 months of concurrent data during the period 1975 through 1982 indicated that monthly precipitation at the study site is greater than that measured at the Little Hills Station if the monthly precipitation was less than 0.95 inches, and smaller than that measured at the Little Hill Station if the monthly precipitation was greater than 0.95 inches. This is in contrast to period studies by WCC (1982) and Wymore (1979) which indicated a general relationship of precipitation increase with elevation. We have used the correlation estimated for this study to modify the Little Hills precipitation data to obtain a long-term (30-year) record at the retorted shale disposal pile site.

Similarly, monthly average air temperature data provided by Cathedral Bluffs at the site were correlated with concurrent monthly average air temperatures at the Little Hills Station. This relationship showed that average monthly air temperature at the site is greater than that measured at the Little Hills Station, based on 48 months of concurrent data. We have used the correlation relation obtained in this study to make estimates of long-term air temperature at the site (Table 3), based on the Little Hills Station.

Site estimates of wind speed (Table 4) and relative humidity (Table 5) were made using average monthly data available at Grand Junction correlated with average monthly data at the site provided by Cathedral Bluffs. Table 6 summarizes the relationship used for estimating monthly long-term precipitation, average air temperature, wind speed and relative humidity at the retorted shale pile disposal pile site.

Runoff is expected to occur from the retorted shale disposal piles' sloping surfaces. Runoff values used in the water balance estimates were based on

data from UOC revegetation plots (Berg and others, 1978; 1979; Harbert and Berg, 1978; and Kilkelly, 1981). Runoff estimates for the years 1976 through 1980 are summarized on Table 7 for Process B retorted shale, 15 and 30 cm soil over retorted shale and retorted shale treatment with a chemical mulch. Annual runoff for the test plots was about 2 inches. We estimated using USGS data for Cottonwood and Sorghum Gulches for the period 1974 through 1981 that annual runoff for this part of the Piceance Basin is less than 0.1 inches and averages about 0.05 inches. The post-reclamation retorted shale disposal pile was assumed to behave similarly to the existing runoff characteristics of Cottonwood and Sorghum Gulches. The amount of monthly precipitation which would run off was estimated based on empirical runoff coefficients. The curve number approach (SCS, 1972) was used.

Evapotranspiration rates in the study area were estimated independently and compared to previous estimates by Wymore (1979). Independent estimates of evapotranspiration for this study were based on data derived from using soil moisture data collected on UOC's Process B retorted shale revegetation plots during the period 1977 through 1980 (Berg and others, 1978, 1979; Harbert and Berg, 1978; and Kilkelly, 1981). Crop growth stage coefficients were estimated for the vegetation growing in the UOC test plots. This vegetation primarily consisted of salt-tolerant shrubs with grasses. The seasonal variation in crop growth stage coefficients from the test plots is compared to the growth stage curve for drought-resistant grasses (Figure 19). The coefficients from the UOC test plots were used in the modified Blaney-Criddle Method (SCS, 1970) to estimate growing season evapotranspiration rates.

Average annual evapotranspiration during the April-through-October growing season was estimated to be about 20.6 inches at Elevation 6900 feet (Table 8). This is compared to previous estimates at the study site by Cathedral Bluffs of about 23.3 inches. These values of evapotranspiration are for types of vegetation growing on Union Process B test plots, assuming

that rainfall was not limiting. Actual evapotranspiration rates are often limited by rainfall and are lower than those given above. Non-growing season (November-through-March) evapotranspiration was assumed to be zero for purposes of this study.

During construction, when no vegetation has yet grown, evaporation was assumed to occur from the wet shale surface. Studies by Veihmeyer (1953) and Veihmeyer and Hendrickson (1955) have shown that evaporation from a wet soil surface is about the same as from a free water surface. Additionally, evaporation from a soil surface was shown not to reduce the moisture content to the permanent wilting percentage in the top 1-foot layer of soil. The loss of moisture in the lower depths through evaporation is generally insignificant on a bare soil. Therefore, the model assumed that water penetrating the retorted shale disposal pile surface to a depth of over 0.5 foot could not be removed by evaporation.

Monthly free water surface evaporation rates were estimated using an equation by Meyer (1915). This equation uses data on relative humidity, saturation vapor pressure, air temperature and wind speed to estimate evaporation. Input data on wind speed and relative humidity (Tables 4 and 5), were estimated using the correlation relationships shown on Table 6 in conjunction with data from the National Weather Service Station in Grand Junction. Air temperature data were taken from adjusted Little Hills records (Table 3). Predicted annual evaporation rates using the Meyer equation are shown on Table 8.

Retorted shale physical parameters for the uppermost 6 feet of the pile are a function of the geotechnical characteristics of the retorted shale, assumptions regarding geochemical alteration or weathering effects, method of placement and vegetation growing on the pile. The estimates of these parameters are based on laboratory analyses and past experience with Union Process B retorted shale. The uncompacted shale was assumed to have a saturated permeability of 2 feet per day (ft/d), a porosity of 56 percent

and a specific retention of 28 percent. No laboratory tests are known to have been performed on the uncompacted Process B retorted shale. The parameter estimates were based on laboratory tests of similar materials (Morris and Johnson, 1967). The saturated permeability of the compacted shale was measured as 0.09 ft/d, with a porosity of 44 percent and a specific retention of 22 percent. These characteristics of the compacted shale were estimated from recent laboratory tests conducted by Core Laboratories, Inc. on a "wheel-compacted" sample of UOC's Process B retorted shale (UOC 1982). The change in relative permeability versus saturation conditions we used for this analysis are shown on Figure 20.

Parameters of the soil used to cover the retorted shale for purposes of reclamation were estimated from the SCS (1982) and our own soil surveys at your site (WCC, 1976). The reclamation soil was estimated to have a permeability of 5 ft/d, a porosity of 30 percent and a specific retention of 15 percent. The relative permeability versus saturation curve shown on Figure 20 for the wheel compacted retorted shale was used as well for the soil and uncompacted retorted shale.

During-Construction Water Balance. During construction, precipitation will fall on the retorted shale disposal pile. This precipitation may cause runoff; whereas, some or all may infiltrate or temporarily pond and evaporate. Water infiltrating the retorted shale pile surface would probably not be evaporated unless surface cracks occur in the pile. Because no vegetation would be growing on unreclaimed pile surfaces, infiltrated water cannot be transpired. Therefore, the water which enters the pile will increase the in-place retorted shale moisture and/or move downward into the pile.

We estimated the quantity of water per unit area which might enter the unreclaimed retorted shale disposal pile during construction. The retorted shale disposal pile will take about 45 years to construct. Because precipitation inputs were assumed to occur randomly, we used the 20-year sequence of precipitation during the period 1951 through 1970 (see Table 2). This

time-series sequence was repeated as needed to account for the full 45 years of pile construction.

During construction, it was assumed that precipitation either entered, ran off, or evaporated from the pile surface in the month in which it fell. This is reasonable because snow falling on recently placed hot retorted shale will probably melt. In this manner, the model was applied on a year-round basis for 20 years of data and the results reported for the entire 45-year period.

Using the 20-year simulation period, the monthly water balance of the retorted shale disposal pile surface during construction was calculated, assuming no runoff from the pile. This is a worst case assumption becasue some of the pile will have runoff from sloping areas. Analysis of the results (Table 9) for the 20-year simulation period of the pile indicates that about 1.6 inches of water per year entering the pile during construction. Because reclamation will occur as the pile is constructed, the estimated unreclaimed, reclaimed and total areas exposed to precipitation as a function of time are shown on Figure 21. The simulated during-construction water balance only considered unreclaimed areas. Because only a few unreclaimed acres have sloped surfaces, the total unreclaimed pile area in each year (Figure 21) was exposed to precipitation with no runoff during the 45-year construction time of the pile. During the anticipated 45-year construction period, it is estimated that approximately 627 acre-feet of water will be added to the pile from precipitation falling on the unreclaimed portion of the pile (Table 10). This 627 acre-feet increased the initial retorted shale moisure from about 17.5 percent by volume to 18.1 percent moisture by volume at the end of pile construction.

About 40 percent of the pile water storage capacity (void space) is used during construction (wetting water plus precipitation). Water would begin to move within the pile when 50 percent of the void space is used.

Supplemental Irrigation During Reclamation Water Balance. Supplemental irrigation may be used on the pile for up to 3 years for any given reclaimed area, with time and amount of each application determined by site monitoring. The expected timing and rates may vary a great deal, depending on slope direction, previous precipitation events, soil amendments used, and age and species of plants.

Irrigation is intended to assist in successful germination and seedling establishment and the early rapid growth of vegetation. However, irrigation would be reduced in the fall to allow shrubs to harden, and thus avoid excessive winter kill. When the plant growth is suitable, irrigation would be removed to allow the vegetation to adjust to natural conditions. The irrigation system may remain in place for at least 3 years. In severe summers, it may be used to ameliorate lengthy drought conditions.

A spray irrigation system would be used to cover the ground surface and provide suitable mositure to shrubs, forbs and grasses. Studies (Berg and others, 1978) have shown that 15 inches of irrigation water applied over a 2-month period were sufficient to establish vegetation in the study plots. Six acre-inches of supplemental irrigation established vegetation in the Cathedral Bluffs field tests (1983) at their site. Eight acre-inches were used in the supplemental irrigation water balance calculations.

We have estimated the amount of water which would enter the retorted shale disposal pile during supplemental irrigation. We assumed that reclaimed access would be irrigated as needed to satisfy consumptive use by vegetation during the months of April through September, with no irrigation in October to allow shrubs to harden. The irrigated areas were estimated from the area available for reclamation (see Table 22) and are shown on Figure 22. Table 11 summarizes the simulated pile water balance during supplemental irrigation for a 30-year period. Table 13 shows that about

4 acre-feet of water would be lost to the pile as the result of supplemental irrigation. This quantity of water would raise the average moisture content of the pile less than 1 percent.

Post-Reclamation Water Balance. The potential for water movement from the reclamation surface into the retorted shale disposal pile was investigated using the analytical unsaturated water flow model discussed above. A 30-year (1951-through-1980) period was used to simulate a long-term water balance of the reclaimed retorted shale disposal pile. The model was run monthly. It was assumed that water penetrating deeper than 6 feet could not be lost by evapotranspiration from the retorted shale; rather, this water represented vertical water movement into the retorted shale disposal pile. The post-reclamation water balance case differs from the during-construction water balance in that evapotranspiration can remove water from below the surface. Snowmelt was not accounted for and precipitation was assumed to be available for infiltration in the month in which it fell.

Runoff was assumed to occur from the gently sloping reclaimed pile top and sloping surfaces. It was assumed for this simulation that any pile benches had become sloped during reclamation and could not trap runoff. The amount of monthly precipitation which would run off was estimated based on empirical runoff coefficients. The curve number approach (SCS, 1972) was used. Based on the USGS gaging station for Cottonwood and Sorghum Gulches, about 0.05 inches of runoff occurs annually, on the average, from this part of the Piceance Basin. This corresponds to a monthly runoff curve number (CN) of 54, which was used during the 30-year simulation period.

Initial retorted shale moisture conditions were assumed to be represented by the cumulative impacts of during-construction, and supplemental irrigation water addition to the retorted shale pits. A summary of these additions is given on Table 13. The final pile moisture content after reclamation averages about 18 percent by volume (14.5 percent by weight

at 78 pcf or about 41 percent of saturation at the assumed porosity of 44 percent. This volume was used as input to the unsaturated flow model for the post-reclamation water balance estimates.

Analysis of the post-reclamation water balance model results (Table 14) for the 30-year simulation period indicates that no water moves below 6 feet. The water balance assumes that the vegetation which would grow on the retorted shale disposal pile consists predominantly of salt-tolerant shrubs and grasses, and that the historical sequence of meteorological inputs would occur.

Conclusions. As a result of our water balance analyses the leachate potential for (1) during-construction is minimal, (2) supplemental irrigation during reclamation is none, and (3) post-reclamation is none. To estimate the effect on the water balance analysis, the analysis was made using precipitation data (13.5 inches/year) from the Little Hills Station only. This analysis also should (1) minimal leachate potential during-construction; (2) none during supplemental irrigation reclamation, and (3) none during post-reclamation.

The sensitivity of outputs from the retorted shale disposal pile water balance model to uncertainties in inputs or estimated model parameters has been considered for two groups of variables. One group of variables involved water leaving the pile as runoff and/or evapotranspiration. The second group involved soil characteristics, which included porosity, permeability, specific retention and initial percent saturation of the retorted shale. Sensitivity for each variable was estimated by making water balance estimates for over 20 or 30 years of data with all other variables held constant except the one under consideration. Results of a typical sensitivity analysis are given in UOC (1982).

In summary, evapotranspiration and runoff are the most critical input variables to the water balance model. The water balance model showed only

minor sensitivity to the retorted shale characteristics. Seepage below 6 feet decreases about 300 percent for each 10 percent increase in evapotranspiration or runoff.

Surface Water Drainage Plan

Operational and environmental regulations dictate the need for surface water controls to protect off-site water resources. Therefore, a preliminary surface water control plan has been developed to:

(1) Collect and retain runoff from the retorted shale disposal pile during construction,

(2) Dispose of retained runoff from the retorted shale disposal pile through treatment and discharge, by evaporation or by use in the process.

(3) Collect and detain runoff from non-retorted shale disturbed areas,

(4) Removal of sediment contributed by runoff from non-retorted shale disturbed areas, and

(5) Divert runoff from undisturbed areas away from disturbed areas and retorted shale disposal pile areas.

Surface water controls would be constructed as needed so they are in place prior to disturbance of the areas associated with construction and placement of retorted shale. Materials native to the area could be used for construction of surface water control structures. These structures would be maintained until they are no longer necessary and then would be removed and the areas of the structures reclaimed.

General Design Criteria. Designs of surface water control structures would comply with applicable state and federal regulations for collection and diversion channel and detention and retention ponds. Dams or embankments, which by virtue of their size would come under the purview of the Colorado State Engineer, would be constructed in accordance with standards and specifications approved by that authority. Smaller embankments would be built to similar standards and specifications appropriate to their size and downstream conditions.

Runoff from disturbed areas during project construction and operation would be collected and conveyed to control ponds. Runoff collected in sedimentation ponds would be detained temporarily for settling solids and then released from the ponds to nearby streams or drainages when applicable standards are met. Runoff from retorted shale disposal pile areas held in retention ponds would be lost by evaporation or seepage, or disposed of after other treatment.

Currently, we envision that the retention ponds would handle runoff from the most downstream exposed face of the retorted shale pile, the pile liner and any intervening natural drainage area. The sides and top of the pile will be benched and graded to retain precipitation. Final reclamation will result in the top of the pile being gently sloped to the west, east, and north. The detention (sedimentation) ponds would handle runoff from the sides and top of the reclaimed parts of the pile as it reaches its maximum height and is gradually constructed down and along the valleys of Cottonwood and Sorghum Gulches.

The following sections summarize the criteria and assumptions that would be used in formulating design and operational policies for the various elements of the surface water control system.

Pond/Embankment Design.

(1) Detention ponds will not be lined because the suspended solids sediment contained in runoff from disturbed non-retorted shale areas are not hazardous.

(2) The runoff volumes resulting from the 25-year, 24-hour precipitation event will establish the design volume for detention (sedimentation) ponds, and runoff volumes resulting from the 100-year, 24-hour precipitation event will establish the design volume for retention ponds.

(3) Detention pond emergency spillways will be capable of safely passing the peak flow rate caused by the 100-year, 24-hour precipitation event.

(4) Volume allocated for storage of sediment in both retention and detention ponds will be equal to the estimated volume of sediment accumulation for a 3-year period or the life of the structure, whichever is shorter.

(5) Pond crest elevation will be increased by 1 foot for freeboard.

(6) Pond embankment cross-sectional design will be based upon geotechnical as well as hydrologic considerations.

Pond Operation and Maintenance.

(1) Runoff entering detention ponds will be held in the ponds until suspended solids concentrations meet the State of Colorado's National Pollutant Discharge Elimination System (NPDES) standards permissible for discharge.

(2) Detention (sedimentation) pond pools will be drawn down immediately after adequate clarification is achieved, as described above.

(3) Detention (sedimentation) pond pools will normally be dry prior to runoff events. If prolonged, minor runoff (such as from snowmelt) occurs, the ponds are to be frequently or continuously decanted, as permissible, to maintain adequate flood pool storage volumes.

(4) Runoff entering retention ponds will be conveyed to the appropriate location on-site for evaporation, treatment or reuse (non-benefical).

(5) Accumulated sediment in both detention and retention ponds will be removed when between 60 to 80 percent of the sedimentation design capacity is reached.

Ditch/Channel Design.

(1) Ditches will be designed to maintain non-scouring velocities for the design event. The maximum design velocity for unlined channels depends upon the type of material through which the ditch passes (Table 15).

(2) Collection and diversion ditches will be assumed to convey water transporting silts and colloidal size clays. Ditches built from detention pond decant outlets will be assumed to convey sufficiently clear water to comply with NPDES specifications.

(3) Where flow velocity is estimated to exceed limiting velocity, riprap or other lining material will be used for channel protection.

(4) Design velocities will be kept below critical velocity wherever practical.

(5) For sub-critical flow conditions, generally a freeboard of approximately 20 percent of the depth or 1.0 foot, whichever is greater, will be added to the channel depth. For super-critical flow conditions, adequate freeboard will be estimated for design purposes by considering alternate depth and velocity head.

(6) All diversion ditches (such as bypasses for runoff from undisturbed areas around disturbed areas or facilities) will be designed to accommodate the rainfall event appropriate for the life of the structure or, for the case where a diversion ditch reduces the contributing drainage area to a pond, the precipitation event which the pond's emergency spillway is designed to accommodate.

Design criteria based on life of the structure would include the following:

Life of Structure	Design Flood
≤10 years	25 years
10 to 20 years	50 years
≥20 years but not permanent	100 years
Permanent	Maximum Probable

(7) Permanent diversion channels will be sized using peak discharge resulting from the probable maximum precipitation from a 6-hour local storm.

Design Hydrology and Sediment Estimates. The design of a surface water control system is governed by many considerations. Our preliminary design surface water controls has taken into account the natural as well as human-induced basin characteristics which affect runoff production in Cottonwood Gulch and Sorghum Gulch. The unit hydrograph techniques outlined by the SCS (1972) were used to estimate peak discharge resulting from the probable maximum precipitation event. For all other estimates of peak discharge rates used to estimate channel geometry and spillway sizes, techniques outlined by the SCS (1977b) were used.

The probable maximum precipitation (PMP) estimates were based on a technique described by Hansen, Schwarz and Riedel (1977). Estimates of on-site precipitation for recurrence intervals from 10 to 100 years were obtained from Miller, Fredrick and Tracey (1973). The three precipitation events used in developing this drainage plan include: (1) 6-hour local PMP storm of 8.27 inches; (2) 100-year, 24-hour storm of 2.6 inches; and (3) 25-year, 24-hour storm of 2.1 inches.

Sediment generated from natural as well as areas disturbed by the project was estimated using the Universal Soil Loss equation described by the SCS (1977a).

Retorted Shale Disposal Pile Surface Water Control. The surface water control system for Cottonwood Gulch and Sorghum Gulch would consist of three basic components: (1) diversion of runoff in channels from undisturbed areas around the pile; (2) collection of runoff contaminated with retorted shale in retention ponds; and (3) collection of runoff from those pile areas undergoing reclamation into detention (sedimentation) ponds. The locations of these three component facilities associated with this surface water control system are shown on Figure 23.

The first component would consist of a series of diversion channels located in the upper drainage of Cottonwood Gulch and the adjacent area in

Sorghum Gulch just upstream from and to the sides of the pile (Figure 23). Channel DC-1 would divert runoff from the undisturbed area between the upstream toe of the proposed retorted shale disposal pile in Cottonwood Gulch and the drainage divide. This runoff would be diverted temporarily to an adjacent watershed. Channels DC-3 and DC-4 would divert runoff from the undisturbed part of Sorghum Gulch upstream of the pile. Diversion channel DC-1 is temporary, with a life of approximately 5 years, after which its use could be discontinued. Diversion channels DC-3 and DC-4 would be permanent, because the pile ultimately will block the existing channel of Sorghum Gulch.

Construction of channel DC-1 should occur prior to any pile construction activities in Cottonwood Gulch. Channels DC-3 and DC-4 should be constructed before any pile construction activities would begin in Sorghum Gulch, or approximately 12.5 years after the initiation of pile construction.

Because channels DC-3 and DC-4 would be the only permanent diversions, they were sized using the resultant peak discharge from a 6-hour local PMP storm. Channel DC-1 was sized to convey the peak discharge resulting from 25-year, 24-hour storm events. A summary of design criteria and general channel details for these channels are given on Table 16.

The second component would control "contaminated" runoff from the retorted shale disposal pile liner, the exposed retorted shale faces during pile construction, and areas being cleared and harvested for topsoil. This surface water control component would consist of a series of compacted retorted shale lined retention ponds just downstream of the retorted shale disposal pile liner. As pile construction continues to migrate down the valley, the liner would be maintained about 500 to 1000 feet in advance of the pile.

The ponds in this component were sized to retain the storm runoff resulting from a 100-year, 24-hour precipitation event. All ponds were designed to

provide an additional capacity to store approximately 3 years of sediment inflow. This sediment storage capacity was reduced proportionally for ponds with expected lifespans less than 3 years.

The retention ponds, except ponds RP-7 and RP-20, were located so runoff would be directed to them by gravity over existing topography. Ponds RP-7 and RP-20 are located so that, in order to to collect runoff from all the area desired, a channel would have to be constructed at the locations shown on Figure 23. Channels DC-7 and DC-16 would be sized to carry the peak discharge resulting from the 100-year, 24-hour precipitation event. This criterion was used in order to be consistent with the retention storage available in ponds RP-7 and RP-20.

The estimated quantities of runoff and sediment collected in any particular retention pond are relatively sensitive to the distance the liner is maintained in advance of the pile face. Table 17 summarizes general details of the retention ponds, including a comparison of operation with the liner 500 and 1000 feet in advance of the pile.

The life of any individual retention pond would be a function of pile advance rate. Based on the assumed pile construction discussed previously, a summary of approximate time sequencing of retention ponds is provided on Table 18.

The third component would collect runoff from areas in the process of being reclaimed. This surface water control component would consist of a series of collection channels and detention ponds. These ponds generally would be located along the east and west sides of the retorted shale disposal pile (Figure 23). These locations were selected to provide for collection of runoff which will migrate in an easterly direction toward Sorghum Gulch and in a westerly direction toward Cottonwood Gulch. As currently envisioned, the drainage divide on the reclaimed retorted shale disposal pile would

have approximately the same alignment as the divide which now separates these gulches.

The detention ponds were sized to provide a capacity to store the runoff resulting from a 25-year, 24-hour precipitation event. Additionally, pond capacity would be provided to store 3 years of estimated sediment inflow.

Spillways for the detention ponds would consist of perforated riser pipes capable of passing the 100-year, 24-hour storm runoff without overtopping the dam. In addition to the maximum water surface elevation estimated during the 25-year storm event, an additional 1 foot of freeboard was added to estimated embankment heights. Embankment heights for both the detention and retention ponds that were 10 feet and higher and with volume greater than 50 acre-feet would require permits from the Colorado State Engineer's Office. By reducing contributing drainage area and spacing ponds closer together, the embankment heights could be reduced to less than 10 feet.

The storage capacity of each detention pond on the east side of the pile was based on a typical pond bottom of 120 feet by 40 feet with 2:1 (horizontal to vertical) sideslopes. Ponds on the east side of the pile would be located in natural depressions blocked by an embankment.

Ponds identified as DP-4, DP-5, DP-14 and DP-15 are also identified as retention ponds RP-6, RP-7, RP-19 and RP-20, respectively (Figure 23 and Tables 17 through 20). Because of their locations, these ponds would be used initially as retention ponds and later as detention ponds. By installing the spillway pipe when the embankment is constructed and blocking it off during the period that the pond is being used for retention, it later could be converted for use as a detention pond. By removing any remaining retorted shale from the bottom of the pond and opening the spillway, it then could serve as a detention pond.

The spillway riser pipe would be perforated to the extent necessary to provide adequate detention time and still drain the pond within 10 days after precipitation stops. The spillway pipes through the dams on the east and west sides of the pile would discharge to a riprap channel or pipe and be carried to the valley bottom of the adjacent natural drainageway. General details of the proposed detention ponds are shown on Table 19.

The collection channels associated with this surface water control component would be located along the east and west perimeters of the pile to collect runoff and convey it to a detention pond. These channels would be sized to convey the discharge resulting from the 25-year, 24-hour precipitation event, unless used as collection channels in the retention pond system. General details of these collection channels are given on Table 16.

The detention ponds would be constructed to collect runoff from the pile top and side surfaces as they are being reclaimed. The time sequencing for the detention ponds is given on Table 20. Once reclamation is completed, the use of the detention ponds can be discontinued and these areas can be reclaimed. For purposes of this plan, reclamation was assumed to require approximately 2 to 3 years to complete.

Spring and Seep Survey

No springs or seeps were noted during our field surveys conducted in the spring and again in the fall of 1983. Field studies included walking the floors of Cottonwood and Sorghum Gulches in an effort to locate the presents of springs or seeps. These particular areas were selected for field reconnaissance based on vegetation cover present on aerial photographs of the proposed retorted shale disposal pile site.

A review of information available in our files indicates 9 springs have been locoated in the vicinity of the Cathedral Bluffs lease bound. Locations of these springs are given on Figure 26.

During the field survey in the spring of 1983, snow was still present and melting on the lease area, probably accounting for much of the flow noted in portions of Cottonwood and Sorghum Gulches. During the fall survey, flow was noted at various locations in both gulches. This flow generally seemed to emerge from the alluvium just upstream of the bedrock outcrop on the gulch floor. This suggests that the emergence of flow from the valley bottom is related to these outcrops and is probably alluvial flow over the bedrock. Additionally, no flow was noted emerging from the gulch walls further supporting the judgment that the flow was alluvial flow coming to the surface.

Flow rates measured during the fall survey in those portions of the gulch floors where surface flow was present were less than 0.5 gpm. In some cases no flow was noted, only standing water or moist soil. The most significant number of channel reaches with moist soil, standing water or flowing water were in the lower halves of each gulch. A small number of channel reaches with moist soil and one with flowing water were noted in the upper half of Sorghum Gulch.

The flow noted in the upper half of Sorghum Gulch would be diverted into the East Fork of Sorghum Gulch. The rock material to be used to fill the steep-walled portions of both gulches, prior to depositing Zone I retorted shale, may provide adequate drainage for flows observed during our field surveys.

TOPSOIL EVALUATIONS

Introduction and Summary

We made a preliminary evaluation of the amount and quality of topsoil available for use in reclamation of the retorted shale pile. Data from the study is summarized on Figure 24 and Table 21.

Our study generally indicated soils typical of the study area are loamy and free of toxic concentrations of salts, sodium, selenium, and boron. They generally are of good quality for use in reclamation. A limiting characteristic of one of the soils for this use is high coarse fragment content. Soil depths are highly variable. They are usually less than 16 inches deep on ridges and steep sideslopes under pinyon and juniper; 20 to 40 inches deep on gentle sideslopes under sagebrush and grasses; and greater than 60 inches deep in draws under rabbitbrush, other shrubs and grasses.

Topsoil stripping depths range from 0 to 5.0 feet or more. The dominant soils in the study area are shallow and have stripping depths of 0.5 to 1.3 feet.

Methods

Soil mapping and soil descriptions were obtained from the recently published Soil Survey of Rio Blanco County Area, Colorado, Soil Conservation Service (SCS) and Bureau of Land Management (BLM), 1982.

Chemical and physical soil laboratory data were obtained from a report by Woodward-Clyde Consultants and correlated to the extent possible with soil types mapped on the study area by the SCS. The texture of selected samples from the test pits excavated for this study was estimated, and the soil pH of some of those samples were measured and correlated with data obtained

for the 1976 agronomic soils report (WCC, 1976). Chemical and physical parameters used in the analysis of topsoil suitability included texture, coarse fragment content, moist and dry consistence, pH, electrical conductivity (EC), sodium adsorption ratio (SAR), selenium (Se) content, boron (B) content, and percent carbonates. Wyoming Department of Environmental Quality (WDEQ) Land Quality Division Guideline No. 1, Topsoil and Overburden (undated) was used as a reference to determine criteria for suitability of topsoil and to assign quality ratings to soil material.

Topsoil stripping depths were estimated based on the results of the suitability analysis and soil horizon (layer) thicknesses and depths as reported by the SCS. It appears the use of pan scrapers and/or bulldozers would be feasible on all areas since soil slopes are no more than 50 percent.

Dominant Soils

Forelle Loam. This deep, well drained soil is formed in calcareous eolian and alluvial material derived from sedimentary rock on terraces and uplands whose slopes are 3 to 8 percent. Typically, the surface layer is loam about 4 inches thick. The subsoil is loam and clay loam about 17 inches thick. The underlying material is loam to a depth of 60 inches or more. Accumulations of carbonates occur at depths of 16 to 40 inches. The soil typically has little or no coarse fragments throughout.

Permeability is moderate and available water capacity is high. EC is less than 2 mmhos/cm and pH is 6.6 to 9.0 in the upper 21 inches and 7.9 to 9.0 in the lower 39 inches. The hazard of water erosion on this soil is moderate.

Recommended stripping depth is 5.0 feet. The soil has no limiting characteristics for use as topsoil.

Piceance Fine Sandy Loam. This moderately-deep, well-drained soil is formed in eolian and colluvial material derived from sandstone on uplands and broad ridgetops whose slopes are 5 to 15 percent. Typically, the surface layer is fine sandy loam with less than 1 percent fine channers and is about 4 inches thick. The subsoil is loam with 5 to 10 percent channers, and is about 18 inches thick. The underlying material is channery loam with 35 percent channers, and is about 8 inches thick. Sandstone bedrock is at a depth of about 30 inches. Accumulations of carbonates occur at depths of 22 to 30 inches.

Permeability is moderate and available water capacity is moderately low. EC is less than 2 mmhos/cm and pH is 7.4 to 8.4 in the upper 22 inches and 7.9 to 8.4 in the lower 8 inches. The hazard of water erosin on this soil is moderate to high.

The recommended stripping depth is 2.5 feet or to bedrock, whichever occurs first. The soil has no limiting characteristics for use as topsoil.

Redcreek Sandy Loam. This shallow, well-drained soil is formed in residual and eolian material derived from sandstone on ridges and ridge sideslopes whose slopes are 5 to 30 percent. Typically the surface layer is sandy loam about 4 inches thick. The subsurface layer is sandy loam about 7 inches thick. The underlying material is channery sandy loam about 5 inches thick. Sandstone bedrock is at a depth of about 16 inches.

Permeability is moderately rapid and available water capacity is very low. EC is less than 2 mmhos/cm and pH is 7.4 to 8.4 in the upper 11 inches and 7.9 to 8.4 in the lower 5 inches. The hazard of water erosion on this soil is moderate to high.

The recommended stripping depth is 1.3 feet or to bedrock, whichever occurs first. The soil has no limiting characteristics for use as topsoil.

Rentsac Channery Loam. This shallow, well-drained soil is formed in residuum derived from sandstone on ridges and ridge sideslopes whose slopes are 5 to 30 percent. Typically the surface layer is channery loam with about 25 percent sandstone channers and 10 percent flagstones, and is about 4 inches thick. The underlying material is extremely flaggy loam with about 80 percent sandstone channers and flagstones, and is about 7 inches thick. Sandstone bedrock is at a depth of about 16 inches.

Permeability is moderately rapid and available water capacity is very low. In the upper 5 inches, EC is less than 4 mmhos/cm and pH is 7.4 to 8.4. The hazard of water erosion on this soil is moderate to high.

The recommended stripping depth is 0.5 feet. The soil is considered unsuitable for use as topsoil below this depth because of high channer and stone content.

Soils of Minor Extent

The Yamac, Blazon, Moyerson, Patent, Work, and Zoltay soils occur on the study area to a minor extent. These inclusions in the four soil map units have not been delineated separately even though their characteristics are dissimilar to those of the major soils.

The Yamac soils are similar to the Forelle soils except that they have 5 to 10 percent channers throughout and lack a clay loam subsoil. The Blazon soils are shallow over fractured shale. Textures are loams and clay loams with 15 to 40 percent channers and gravel. The Moyerson soils are shallow and clayey, with a stony surface. Patent soils are greater than 60 inches deep, have loam and fine sandy loam textures, and lack evidence of soil development. Work soils are greater than 60 inches deep, have loam and clay loam textures, and have accumulations of clay and carbonates below 10 inches. Zoltay soils are similar to Work soils but have a thicker organic surface layer.

Topsoil stripping depths for these minor soils vary greatly. Generally, the Blazon and Moyerson soils are considered poor quality or unsuitable; Yamac and Work soils have good quality topsoil to depths of 10 to 22 inches; and the Patent and Zoltay soils have good quality topsoil to depths of 40 to 60 inches. Limiting characteristics for use as topsoil differ among these soils but include: high coarse fragment content, high pH and EC, clayey textures, and very hard dry consistence.

Because these soils have not been separately delineated in mapping, it is not possible to quantify their location and areal extent on the study area. It is estimated that topsoil material recovered from these soils would be about 440 acre-feet (but may be as much as 790 acre-feet).

Soil Map Units

Four soil map units were delineated on the study area (see Figure 24, Topsoil Stripping Map). Three of the four map units are consociations (comprised of one dominant soil series).

Map unit 33, Forelle loam, 3 to 8 percent slopes, consists of 85 percent Forelle loam and 15 percent inclusions. The potential plant community on this map unit is dominantly western wheatgrass, prairie junegrass, big sagebrush, Douglas rabbitbrush, streambank wheatgrass, and needle and thread. This map unit has been designated by the SCS as Prime Farmland (If Irrigated). This means that the soils in this map unit qualify as prime farmland soils but they "are not presently irrigated or are not irrigated with an adequate supply of water" (SCS and CSU, 1979).

Map unit 64, Piceance fine sandy loam, 5 to 15 percent slopes, consists of 85 percent Piceance fine sandy loam and 15 percent inclusions. The potential plant community on this map unit is dominantly bluebunch wheatgrass, western wheatgrass, big sagebrush, serviceberry, prairie junegrass, and sand lupine.

Map unit 70, Redcreek-Rentsac complex, 5 to 30 percent slopes, consists of 60 percent Redcreek sandy loam, 30 percent Rentsac channery loam, and 10 percent inclusions. The potential plant community on this map unit is dominantly pinyon and juniper with an understory of beardless wheatgrass, Indian ricegrass, serviceberry, mountainmahogany, sedges, and big sagebrush. Many areas have been chained to improve forage production.

Map unit 73, Rentsac channery loam, 5 to 50 percent slopes, consists of 80 percent Rentsac channery loam and 20 percent inclusions. The potential plant community on this map unit is dominantly pinyon and Utah juniper with an understory of Indian ricegrass, beardless wheatgrass, mountainmahogany, and prairie junegrass; big sagebrush, bitterbrush and serviceberry are also present to a smaller extent. Some areas have been chained to improve forage production.

Topsoil Volume Summary

Approximately 1213 acre-feet of topsoil appears to be recoverable from dominant soils on the 1095-acre study area. An additional 440 acre-feet of soils may be recovered from minor soils (inclusions). The estimated average replacement depth of topsoil on the surface of the retorted shale pile and water diversion channel is 1.1 to 1.8 feet (average 1.4 feet).

The quality of the topsoil is considered good. Based on the Order 3 soil survey by the SCS and laboratory results correlated with soils on the study area, soil characteristics do not warrant the separation of topsoil into two lifts during stripping operations.

Complete topsoil recovery may not be possible in areas where rock outcrops are intricately intermixed with soil material, especially on steeper gulch sideslopes. Therefore, the topsoil volume given on Table 21 could vary by as much as 5 to 10 percent.

RECLAMATION

Introduction

This preliminary reclamation plan addresses the stabilization of the retorted shale disposal area through revegetation. Revegetation includes such topics as disposal techniques, topsoil stockpiles, seedbed preparation, species selection and post revegetation monitoring.

The revegetation program is a mitigative measure to restore the retorted shale disposal pile to a productive condition. Disposal pile revegetation should reduce wind and water erosion and should lessen aesthetic impacts by blending these areas in with the vegetation of surrounding terrain.

The goal of the revegetation program is to establish, as quickly as possible, a permanent self-sustaining vegetation cover that would eventually become an integral part of the surrounding ecosystem. The revegetation program should be flexible so that improved methods, techniques or even unforeseen developments can be accommodated promptly. Many research studies through the academic community are currently underway that may provide new insights or approaches that could improve the reclamation effort.

The preliminary disposal plan developed for this study attempts to reduce the amount of disturbed area in the disposal area at any given time. As the disposal pile becomes larger, additional areas will be prepared. The revegetation process would begin when permanent surfaces are available for planting and continue area by area until the final surface of the pile has established a suitable vegetation cover.

Previous Revegetation Studies

Some significant findings from Union Oil Company's retorted shale research plots are summarized below since Cathedral Bluffs is considering using the UOC Unishale B retort. UOC has been involved in revegetation research of Process B retorted shale for the last 8 years in cooperation with the Agronomy Department of the Colorado State University at Fort Collins. Approximately 12 technical reports have been produced from this research.

Chemical and Physical Properties. Early studies (Berg et al 1976) established that retorted shale from the Union Process B, which has a loamy texture, is high in soluble salts, has an adequate pH, and is low in available phosphorus and nitrogen. Other mineral nutrients are low to adequate. The major problems encountered in establishing vegetation on retorted shale are the shale's low fertility, high sodium absorption ratio, and high soluble salt content. These conclusions were used to design field tests of plant growth in order to identify potentially suitable species for reclamation of retorted shale.

Fertility and Infiltration. The addition of phosphorus and nitrogen to retorted shale overcomes nutrient deficiencies and satisfactory growth is achieved. Comparison of water infiltration rates for native soils and various treatments of retorted shale have been measured by McQueen (1963). The infiltration rates for native soil in the Piceance Basin have been measured at approximately 3 cm/hr on bare soils and as high as 7 cm/hr on soils with heavy litter cover (Meiman 1973). These values compare favorably with Process B retorted shale infiltration rates.

Soil Salinity. Electrical conductivity determinations (which are measurments of salt concentrations) have shown that unleached Union Process B retorted shale averages 7 to 9 mmhos/cm of saturated extract. Soluble salts in soils at conductivity readings greater than 4 mmhos/cm generally have adverse effects on seed germination, root penetration, and growth

of crop plants. Studies performed on some plant species native to the semi-arid region of the oil shale country have shown them to tolerate soil salt concentrations many times higher than 15 mmhos/cm (McKell et al 1979).

Process B retorted shales continue to break down to smaller particle sizes under natural weathering processes. During this process additional particle surface area comes into contact with water and soluble salts are released. Preliminary studies indicate that these salts are released over several seasons.

High soluble salts concentrations in retorted shales are lowered by leaching the surface with sufficient water to carry the salts well below the root zone (Berg, 1973 a,b; Berg et al 1976). In later studies Harbert and Berg (1978) and Kilkelly et al. (1981) have reported a good cover of perennial species on their Union Process B retorted shale test plots where initial leaching of surface salts was done.

Surface Treatments. Research results from the UOC field study plots indicate that vegetation is established on all treatments ranging from bare retorted shale to 12 in of soil over retorted shale. However, plant cover values are consistently higher in the soil over retorted shale plots. Over a 6 yr analysis, plant cover values were greatest with 6 in of soil cover over retorted shale, followed by the mulch treatment and then bare Process B retorted shale. In these evaluations shrub cover generally has continued to increase with some decrease in perennial grass cover where bare retorted shale was the growth medium. Topsoil controls have maintained a more even balance of grasses, forbs, and shrubs. The plots with soil over retorted shale begin with substantial amounts of grasses and forbs but gradually come to resemble the bare retorted shale plots.

Surface Moisture and Surface Runoff. Moisture profiles in the Process B retorted shale plots have shown recharge after winter precipitation to

levels up to 25 percent (by volume). Depletions down to about 10 percent of potential result during the growing season due to evapotranspiration.

After 6 yr of measurements, surface runoff amounts have generally been small. The runoff quality has been good, and salinity and sodium hazards to vegetation have been rated as low. In addition, sediment yields after vegetation establishment have also been considered low (Kilkelly, 1981).

Successful Species. The 1979-1980 field plot evaluations show that several species have become established to some degree (Kilkelly, 1981). These species include western wheatgrass, intermediate wheatgrass, crested wheatgrass, basin wildrye, winterfat, fourwing saltbush, Lewis flax and cicer milkvetch. In these test plots the most successful species are salt and drought tolerant species.

Conclusions. For Cathedral Bluffs' consideration, research efforts with Union Oil Process B retorted shale show that problems and available solutions leading to successful reclamation are: (1) low fertility of retorted shale improved by nitrogen and phosphorus fertilization; (2) high surface temperatures of retorted shale lowered by mulching, soil cover, or vegetation establishment; and (3) high soluble salt content of the retorted shale reduced by leaching, or avoided through a soil cover or the use of selected salt-tolerant species.

Major Reclamation Issues

Chemical and Physical Properties of Retorted Shale. Chemical and physical properties of retorted shale determine to a large extent the reclamation strategy and dictate the direction of the program. Those properties which are important considerations are: (1) particle size and distribution; (2) pH; (3) electrical conductivity; (4) nitrogen and phosphorus or other nutrient deficiencies; and (5) prescence of heavy metals and organics.

Plant Species Selection. Species selection is also an important consideration because of the importance of matching plant species characteristics with the above physical/chemical properties.

Although a number of plant species have been grown successfully on retorted shale test plots, concerns have arisen as to long-term establishment of the vegetation. There are three reasons for this concern:

(1) All test plots to date have been fairly shallow and the possibility exists that roots, especially of shrubs, have penetrated the shallow retorted shale layer into the subsoil.

(2) Revegetation test plots are not old enough to evalute the potential for long term establishment and reproduction of a self-sustaining plant community.

(3) Results from small tests plots may not extrapolate to large relaimed areas of a commercial operation.

Hydrologic Cycle of Retorted Shale Disposal Pile. The characteristics of the hydrologic cycle of the disposal pile are of interest for two reasons: (1) surface runoff, erosion and possible degradation of water quality of near surface waters; and (2) percolation, leachate production and possible degradation of subsurface water quality. Although there have been several studies conducted to provide data on runoff and leachate quality, field test programs of proper size and design are lacking. The measurement and integration of evapotranspiration data to describe the hydrologic cycle has been used to a limited extent but refinements are necessary.

Soil Cover and Depth over Retorted Shale. The need for a soil cover of some nominal depth has been proposed by various researchers and regulatory

agencies, however, no concensus has been reached. The need for a soil cover of some depth would be governed by research results on different retorted shales, regulatory considerations, and availability of a sufficient quantity of native soil.

Proposed Reclamation Type

Rangeland and Wildlife Habitat. Cathedral Bluffs proposes to return disturbed project lands to rangeland and wildlife habitat. Biological baseline studies indicate that the project area is a chained pinyon-juniper vegetation type. Other associated vegetation types can be generalized in the following plant communities: (1) agricultural fields (hay meadows); (2) lowland sagebrush and greasewood; (3) plateau sagebrush; (4) mixed mountain shrub; (5) pinyon-juniper woodland.

The vegetation within the permit area is a pinyon-juniper type with a mix of shrub and herbaceous understory that provides winter range to game species, especially mule deer. Hay meadows along Piceance Creek provide both fall and spring forage to mule deer. Rangeland use by domestic cattle is very important, both in the hay meadows and native vegetation. A wide variety of songbirds, small mammals and raptors utilize these habitats. The structural diversity of the vegetation determines, to a large extent, the species richness of the area in terms of wildlife.

Properties of Retorted Shale Important to Revegetation

Although Process B retorted shales are low in nutrients and high in soluble salts, cultural practices effectively overcome these potential problems and successful revegetation is achievable. Characteristics of and cultural practices for retorted shale which require special attention include fertility, salt content, soil amendments, color, irrigation, and species selection.

Fertility. Tests for available nutrients indicate that Process B retorted shale is deficient in nitrogen and phosphorus and low in available potassium. This low fertility is initially improved by the application of fertilizers. As vegetation becomes established, the decomposition of newly deposited organic material may aid soil development and improve fertility. Based on previous studies detailed in Kilburn and Bloch (1973) and work performed by CSU and others, preliminary recommendations call for organic matter such as sewage sludge, sawdust, shredded plant material, etc. added to the retorted shale to stimulate microbial activity and aid in the establishment of a nutrient cycle.

Among other factors, the amount of nitrogen necessary as a nutrient amendment will depend upon climate, topographic position, aspect and soil texture (Stevenson 1965). Nitrogen fertilization rates will be dependent upon the type of organic amendment applied to the retorted shale surface, the duration of irrigation, and the specific requirements of those plant species selected for reclamation purposes.

Salt Content. The high salt content of retorted shale is soluble and can easily be lowered to reasonable levels by leaching with water (Berg 1973a); Berg, et al. 1976, 1979). This has been an accepted approach in the Piceance Basin and the approach originally suggested by Colony in its earlier studies at Parachute Creek.

While leaching reduces the salinity content of the upper soil, resalinization through capillary rise can occur in these materials. Studies in the Piceance Basin indicate a tendency for salts leached downward in the shale to migrate upwards to the surface if the salts have not been leached deeply enough to escape capillary pull. A potential solution to this problem consists of placement of a capillary-break layer of material (i.e. gravel) between the retorted shale and a surface layer of topsoil (McWhorter 1973). This layer allows salts in solution to move downward from the root zone, but does not allow any upward movement of the solution.

This system has been tried successfully in some test plots but has not been demonstrated over the long term, and in fact may be showing signs of barrier filling with fine particles which establishes the capillarity anew.

The 3 major drawbacks to the system are the uncertainty of long term benefit, the filling in of the larger spaces by fine material which again establishes a capillary zone between soil and retorted shale, and an adequate source of capillary break material. A different strategy is to employ a heavily compacted zone to retard downward water movement below the root zone and to utilize selected salt-loving shrubs to act as pumps to evapotranspire deeper soil water.

Soil Amendments. The structural characteristics of retorted shale can be changed to improve root penetration and water infiltration. By the addition of organic materials a more friable medium is possible which would lower the pH, lighten the color, and raise the level of available nutrients. In separate experimental plots, Schaal, Berg and Bradshaw (Bloch and Kilburn 1973) used sawdust and peat moss. However, other organic materials such as filter-cake, sewage sludge, manure and ground garbage are prefered because they also stimulate the growth of soil microorganisms (Hersman and Klein 1979). Many other studies indicate the value of these organic materials (Mathers and Stewart 1971, Sooper and Kardos 1971).

In a greenhouse study Williams and Packer (1977) utilized various soil admendments to assess the comparative growth of tall wheatgrass on retorted shale. Of the amendments used, sewage sludge proved most beneficial and was the only one that prevented salt deposition at the surface from capillary action.

Irrigation. In studies to date sprinkler and drip irrigation systems have been used to establish planted species. Drip irrigation systems reduce excessive water losses and control delivery to the plants

(Frishknecht and Ferguson 1979). However, the cost of such a system can be large on a commercial scale. Studies also indicate that supplemental irrigation for shrubs could enhance seedling survival in a revegetation program.

The amount of water required for irrigation is important. Overwatering and frequent watering could result in excessive weed growth and increased competition for water by grasses, weedy species and shrubs, and discourage deep-rooting of shrubby species.

Species Selection. Plant species distributions are governed mainly by adaptations to climate and secondarily by edaphic factors (Good 1953). The selection of species for reclamation should consider these factors along with post-project land-use plans.

In semi-arid climates such as the Piceance Creek basin, seasonal moisture and availability, and water holding capacity of the soils are very critical. Additionally, other factors such as slope, exposure and soil chemical properties are important because of the existing extreme climatic conditions.

The reclamation objectives in these more extreme sites are to reduce erosion and enhance post-project land-use. Species selection therefore, considers adaptations to precipitation regimes, soil chemical and physical properties, plant growth regions, compatability and palatability to different wildlife and livestock requirements and longevity, among others. These characteristics are considered in order to provide a reclamation plan to fit the limitations of the site and the proposed land-use after project development.

Preliminary Reclamation Plan

Disposal Procedures. The currently conceived disposal plan is discussed above under "RETORTED SHALE DISPOSAL." In general, the disposal plan involves transporting and placing most of the premoistened retorted shale with conveyor-fed stackers. The stacker placed material (Zone II) will be placed over a compacted retorted shale blanket (Zone I) and will be covered with a compacted retorted shale blanket (Zone I) and reclamation zone.

Pile Size and Shape. The preliminry disposal plan formulated for this study should reduce potential environmental problems. It includes the following features:

(1) Pile encapsulation with a compacted layer (Zone I) to reduce water infiltration.

(2) Exposed slopes of 4:1 to reduce erosion and runoff, and provide for reclamation surfaces.

(3) Surface area available for revegetation in increments to allow for evaluation of reclaimed areas and adjustments where necessary.

Topsoil Stripping, Stockpiling and Replacement. The native topsoil and associated rock fragment material at the disposal site and other disturbed areas should be removed and reused to the extent possible. Topsoil stripped from the disposal pile area could be transported and used for reclamation areas without stockpiling, or could be stockpiled for future use. If stockpiled, particularly for significant periods of time, the topsoil stockpile surfaces should be temporarily stabilized and protected from wind and water erosion by seeding suitable grass species. Selected species may include tall wheatgrass (Agropyron elongatum); crested wheatgrass (Agropyron cristatum); western wheatgrass (A. smithii); beardless

bluebunch wheatgrass (A. spicatum var. inerme); alfalfa and Utah sweetvetch (Hedysarum borale). An established grass and forb cover will be adequate to protect topsoil stockpiles from erosion until needed.

Stripping depths and topsoil suitability are discussed above under "TOPSOIL EVALUATIONS" and on Figure 24 and Table 21. At least 1 foot of topsoil appears to be available for spreading on the retorted shale pile during reclamation.

Surface Preparation. As sections of the retorted shale pile are completed, irrigation and revegetation could begin. Estimated pile areas available for reclamation at various times into the project are shown on Table 22.

Sewage sludge from the retort facility and nearby towns could be applied to the topsoil retorted shale surface along with inorganic phosphate fertilizers. If selected, these materials should be worked into the upper 6 to 8 in of the final pile surface. Other organic material such as sawdust or organic garbage may be substituted or applied in combination with sewage sludge. This treatment would encourage the development of soil microflora, and improve the structure and water-holding capacity of the rooting medium. Any sludge material added to the retorted shale pile should meet existing regulatory standards.

Surface tillage and seedbed preparation should consist of light or shallow tillage operations using a combination of disk harrow and spike tooth harrow. The final tillage treatment could be performed by a shallow chisel plow on the level contour or by using a lister or rangeland pitter. The purpose is to leave an uneven, erosion resistant surface which would aid water infiltration and enhance germination and establishment of seeded and planted species.

Species Selection. Over 20 plant species have been tested in UOC Process B retorted shale in western Colorado. Since the UOC site is in a mix of

vegetation types with about 14 to 18 in of annual precipitation, the revegetation emphasis is on a mix of shrubby and grass species that are adapted to the C-b Tract area and readily available. Table 18 is a list of suitable species for this area.

Seeding Procedures. Final selection of seeding methods and rates is contingent upon the plant species utilized and current vegetation establishment studies at the C-b Tract area and consultation with the CMLRB staff and land managers. Broadcast seed applications, gauged disk opener drill, hydroseeding and containerized plantings of certain species are all being considered. Results from continuing studies will aid in selecting the best seeding method or combination of methods. Generally, easy access and favorable sites can be drilled and difficult areas hydroseeded. Tubelings would be planted after seed establishment, where needed or desired, in a pattern which approximates native plant distributions.

Supplemental irrigation could be utilized on the pile for up to 3 years, with time and amount of each application determined by site monitoring. We expect the timing and rates to vary a great deal depending on slope direction, previous precipitation events, soil amendments utilized, age and species of plants, but suggested rates are 8 inches the first year.

Irrigation is intended to assist in successful germination and seedling establishment and the early rapid growth of vegetation. However, irrigation must be reduced in the fall to allow shrubs to harden, and thus avoid excessive winter kill. When plant growth is suitable, irrigation should be removed to allow the vegetation to adjust to natural conditions. The irrigation system would remain in place for a total of 3 years to supplement precipitation in dry summers and to ameliorate lengthy drought conditions.

Fertilization - Disposal Pile and Disturbed Areas. Application rates of commercial chemical fertilizers based upon surface soil analysis, agency

recommendations and organic soil amendments applied suggest an 80-100-50 (N-P-K) rate, or N-80 lbs/acre; P-100 lbs/acre; and 50-K lbs/acre. Fertilizers should be applied when reclamation surfaces are available and thereafter in the fall, as needed.

Monitoring. A monitoring program to evaluate "successful reclamation" should be established. The purpose of this program would be to:

(1) provide rapid recognition of problem areas

(2) identify alternative mitigation strategies

(3) establish an unbiased estimator(s) for "success"

(4) establish the methodologies for measuring, analyzing, and interpreting "success" criteria, and

(5) establish the sampling schemes for data collection

The monitoring program should be implemented by qualified personnel with both practical field experience and basic knowledge of plant sciences. Monitoring plant density, plant cover and composition, phenology and seed set, and seedling establishment from planted species should be considered.

GENERAL INFORMATION

Woodward-Clyde Consultants warrants that our services are performed, within the limits prescribed by our Clients, with the usual thoroughness and competence of the engineering profession. No other warranty or representation, either expressed or implied, is included or intended in our proposals, contracts, or reports.

CREDITS

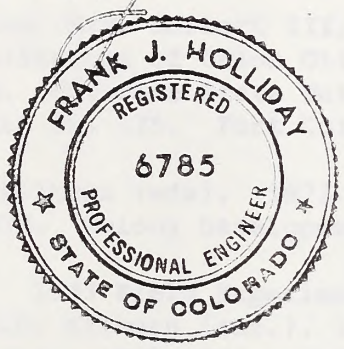
Studies and analyses for this report were made by Mr. Roy Spitzer, site geology, Mr. Kevin Aubry, geotechnical data, Mr. Robert Murphy, hydrological data, Ms. Carolyn Nader, topsoil evaluation, and Dr. Jose Merino, reclamation plan. Information concerning the proposed project was provided by Messrs. Watson and Baker of Cathedral Bluffs Shale Oil Company. This report was reviewed and approved by the undersigned Principal of our firm.

If we may be of further service in discussing the contents of this report, please call.

Frank J. Holliday
Vice President

WLZ:gg

(3 copies sent)



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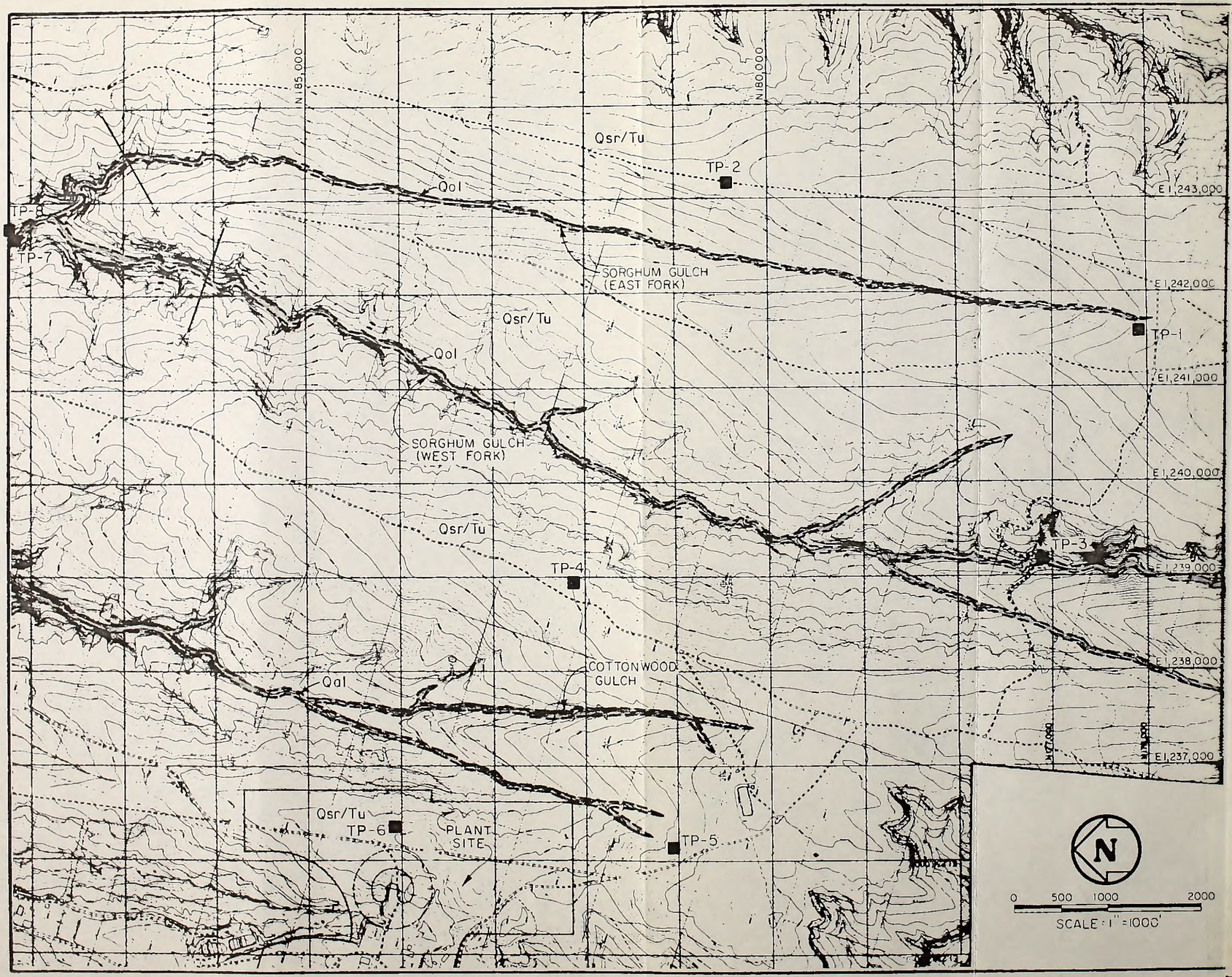


LEGEND

Qal

ALLUVIUM: STREAM DEPOSITED SOILS ALONG THE BOTTOM OF COTTONWOOD AND SORGHUM GULCHES, LOCALLY INTERRUPTED BY BEDROCK OUTCROPS. THE SOILS APPEAR TO BE UP TO A FEW FEET THICK ALONG COTTONWOOD GULCH AND MOST OF SORGHUM GULCH AND CONSIST OF SANDS AND CLAYS CONTAINING COBBLES AND GRAVELS. THE ALLUVIUM COULD BE SEVERAL FEET THICK ALONG THE NORTHERNMOST REACHES OF SORGHUM GULCH.

Qsr/Tu

SLOPEWASH AND RESIDUAL SOILS MANTLING UINTA FORMATION BEDROCK: THE SOILS APPEAR TO BE A FEW INCHES TO A FEW FEET THICK AND CONSIST OF SANDS AND CLAYS. THE BEDROCK APPEARS TO BE MAINLY THIN TO MASSIVELY BEDDED, CLOSELY TO WIDELY JOINTED AND FRACTURED SANDSTONES WITH SUBORDINATE SILTSTONES AND MARLSTONES. THE BEDROCK CROPS OUT IN STEEP CLIFFS AND SLOPES ALONG THE GULCH BOTTOMS, AND LOCALLY ELSEWHERE.

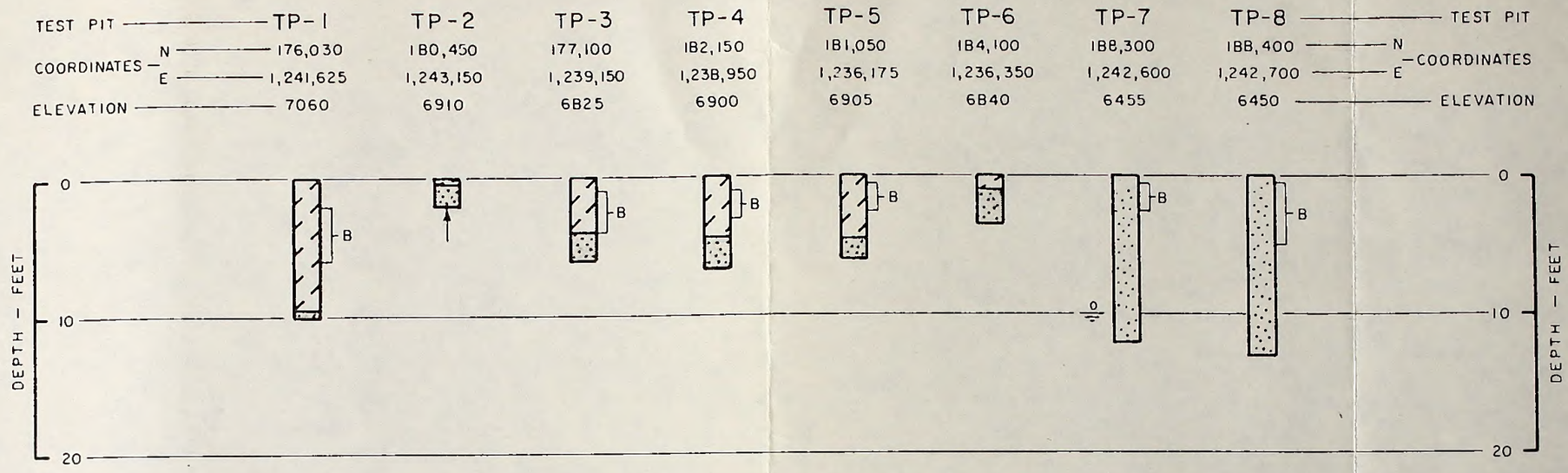
INDICATES APPROXIMATE LOCATION OF NORTHERNMOST BEDROCK OUTCROPS AT BOTTOM OF SORGHUM GULCH. NORTH OF THE LINES THE GULCH BOTTOM IS CONTINUOUSLY BLANKETED BY ALLUVIAL SOILS. SOUTH OF THE LINES THE ALLUVIAL SOILS ARE THIN AND LOCALLY INTERRUPTED BY BEDROCK OUTCROPS.

GEOLOGIC CONTACT, APPROXIMATELY LOCATED.

TEST PIT, APPROXIMATELY LOCATED.

Job No.: 21120-19605	SURFICIAL GEOLOGY MAP
Prepared by: R.H.S	
Date: 4/18/83	

FIG. 1



LEGEND

CLAY, MEDIUM STIFF TO STIFF, SANDY TO VERY SANDY, SILTY TO VERY SILTY, CALCAREOUS, MOIST, TAN, BROWN (CL, CL-ML, CL-SC).

SAND, LOOSE TO MEDIUM DENSE, GRAVELLY TO VERY GRAVELLY, SCATTERED COBBLES, CLEAN TO SLIGHTLY SILTY, MOIST TO WET, BROWN, DARK BROWN (SP, SP-SM).

SANDSTONE, MEDIUM HARD TO HARD, SILTY, WEAKLY TO MODERATELY CEMENTED, MODERATELY WEATHERED, FRIABLE, FINE GRAINED, DRY TO SLIGHTLY MOIST, TAN (BEDROCK) (UINTA FORMATION).

B INDICATES BAG SAMPLE TAKEN FROM INTERVAL SHOWN.

INDICATES PRACTICAL BACKHOE REFUSAL.

0 INDICATES FREE WATER LEVEL AND NUMBER OF DAYS AFTER COMPLETION OF EXCAVATION THAT WATER LEVEL WAS MEASURED.

NOTES:

1. TEST PITS WERE EXCAVATED ON APRIL 5, 1983 WITH A CASE MODEL 580 BACKHOE.
2. COORDINATES AND ELEVATIONS SHOWN ARE APPROXIMATE AND WERE OBTAINED FROM TOPOGRAPHIC MAPS PROVIDED BY CATHEDRAL BLUFFS SHALE OIL COMPANY.
3. SOILS WERE CLASSIFIED IN ACCORDANCE WITH THE UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D 2487).
4. THESE TEST PIT LOGS ARE SUBJECT TO LIMITATIONS, EXPLANATIONS AND CONCLUSIONS OF THIS REPORT.
5. THESE TEST PIT LOGS SUMMARIZE FINDINGS RELIED ON IN FORMULATING THE DESIGN CRITERIA FOR OUR REPORT. THE EXPLORATIONS WERE NOT MADE TO DEFINE CONDITIONS FOR CONSTRUCTION NOR IS THE INFORMATION PRESENTED HEREIN FOR THAT PURPOSE.

Job No. : 21120-19605	TEST PIT SUMMARY LOGS
Prepared by: KEA	
Date: 4/8/83	

FIG. 2

Woodward Clyde Consultants

N

0 500 1000 2000

SCALE 1" = 1000'

SEE FIGURE 8 FOR LEGEND AND NOTES, AND FIGURES 9 AND 15 FOR SECTIONS.

Job No. 21120-19605	DISPOSAL AREA PLAN
Prepared by: R.M.D.	YEAR 5
Date: 8/1/83	

FIG. 3

Woodward-Clyde Consultants

N

0 500 1000 2000

N 185,000

N 180,000

E 1,242,000

E 1,240,000

SORGHUM GULCH (EAST FORK)

SORGHUM GULCH (WEST FORK)

WATER DIVERSION CHANNEL DC-3

WATER DIVERSION CHANNEL DC-4

RUNOFF RETENTION DIKES (TYPICAL)

EL. 6850

EL. 6900

EL. 6970

COTTONWOOD GULCH

POTENTIAL TOPSOIL STOCKPILE AREA (TYPICAL)

WETTING FACILITY

STOCKPILE BENCH

PLANT SITE

POTENTIAL TOPSOIL STOCKPILE AREA (TYPICAL)

A A' B B' D D' E E'

SEE FIGURE 8 FOR LEGEND AND NOTES, AND FIGURES 10 AND 15 FOR SECTIONS.

Job No. : 21120-19605	DISPOSAL AREA PLAN YEAR 12
Prepared by: K.E.A.	
Date: 8/1/83	

FIG. 4

Woodward Clyde Consultants

N

0 500 1000 2000

SCALE 1" = 1000'

N 185,000

N 180,000

E 1,242,000

E 1,240,000

SORGHUM GULCH (EAST FORK)

SORGHUM GULCH (WEST FORK)

WATER DIVERSION CHANNEL DC-3

WATER DIVERSION CHANNEL DC-4

POTENTIAL TOPSOIL STOCKPILE AREA (TYPICAL)

POTENTIAL TOPSOIL STOCKPILE AREA (TYPICAL)

EL. 6850

EL. 6900

EL. 6970

EL. 6970

EL. 7000

COTTONWOOD GULCH

WETTING FACILITY

STOCKPILE BENCH

PLANT SITE

A A'

B B'

C C'

D D'

E E'

SEE FIGURE 2 FOR LEGEND AND NOTES, AND FIGURES 11 AND 15 FOR SECTIONS.

Job No : 21120-19605	DISPOSAL AREA PLAN YEAR 20
Prepared by: R.M.D.	
Date 8/1/83	

FIG. 5

Woodward-Clyde Consultants

N 185,000

N 180,000

E 1,242,000

E 1,240,000

B

B'

C

C'

D

D'

E

E'

A

A'

SORGHUM GULCH (EAST FORK)

SORGHUM GULCH (WEST FORK)

WATER DIVERSION CHANNEL DC-3

POTENTIAL TOPSOIL STOCKPILE AREA (TYPICAL)

RUNOFF RETENTION DIKE (TYPICAL)

POTENTIAL TOPSOIL STOCKPILE AREAS ATOP PILE (TYPICAL)

EL. 6850

EL. 6900

EL. 6970

EL. 7000

WATER DIVERSION CHANNEL DC-4

WETTING FACILITY

STOCKPILE BENCH

PLANT SITE

N

0 500 1000 2000

SCALE: 1" = 1000'

SEE FIGURE 8 FOR LEGEND AND NOTES, AND FIGURES 12 AND 15 FOR SECTIONS.

Job No. : 21120-19605	DISPOSAL AREA PLAN YEAR 30
Prepared by: R.M.D.	
Date: 8/1/83	

FIG. 6

Woodward-Clyde Consultants

N 185,000

N 180,000

E 1,242,000

E 1,240,000

SORGHUM GULCH
(EAST FORK)

SORGLUM GULCH
(WEST FORK)

COTTONWOOD
GULCH

EL. 6900

EL. 6850

EL. 6970

EL. 7000

POTENTIAL TOPSOIL
STOCKPILE AREAS ATOP
PILE (TYPICAL)

WATER DIVERSION
CHANNEL DC-3

WATER DIVERSION
CHANNEL DC-4

WETTING FACILITY

STOCKPILE
& BENCH

PLANT
SITE

A

A'

B

B'

C

C'

E

E'

N

0 500 1000 2000

SCALE 1" = 1000

SEE FIGURE 8 FOR LEGEND AND NOTES, AND FIGURES 13 AND 15 FOR SECTIONS.

Job No. : 21120-19605	DISPOSAL AREA PLAN
Prepared by: K E A	YEAR 40
Date 8/1/83	

FIG. 7

LEGEND

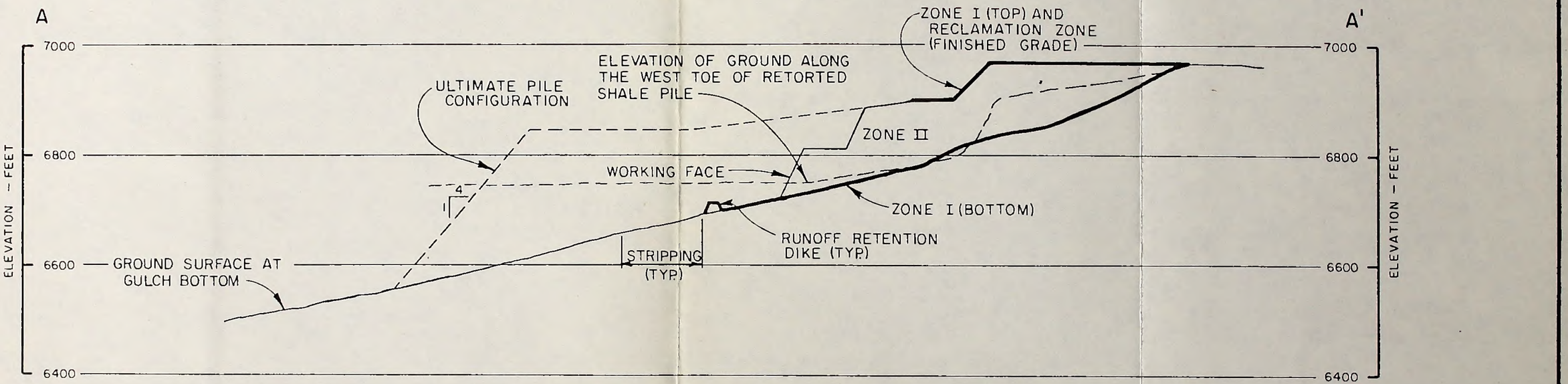
- STRIPPED AREA (TYPICAL)
- ZONE I (BOTTOM) (TYPICAL)
- ZONE I (TOP) AND RECLAMATION ZONE (TYPICAL)
- TEMPORARY COTTONWOOD GULCH PILE SLOPE
- ZONE II, ACTIVE PILE FACE (TYPICAL)
- APPROXIMATE AREA OF 10-FOOT THICK ZONE I SECTIONS (TOP AND BOTTOM)
- POTENTIAL TOPSOIL STOCKPILE AREA

NOTES:

1. SEE FIGURES 14 AND 15 FOR SECTIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.
3. THE DISPOSAL AREA PLANS AND SECTIONS SHOWN ON FIGURES 3 THROUGH 14 ARE TYPICAL CONFIGURATIONS FOR ILLUSTRATIVE PURPOSES AND REFER TO THE DISPOSAL TIMETABLE AND NOTES SHOWN ON FIGURES 17 AND 18, RESPECTIVELY, AND DISPOSAL METHODS DISCUSSED IN THIS REPORT.

Job No.: 21120-19605	DISPOSAL AREA PLAN YEAR 45 (ULTIMATE PILE)
Prepared by: K.E.A.	
Date 8/1/83	

FIG. 8



SECTION A-A' – COTTONWOOD GULCH

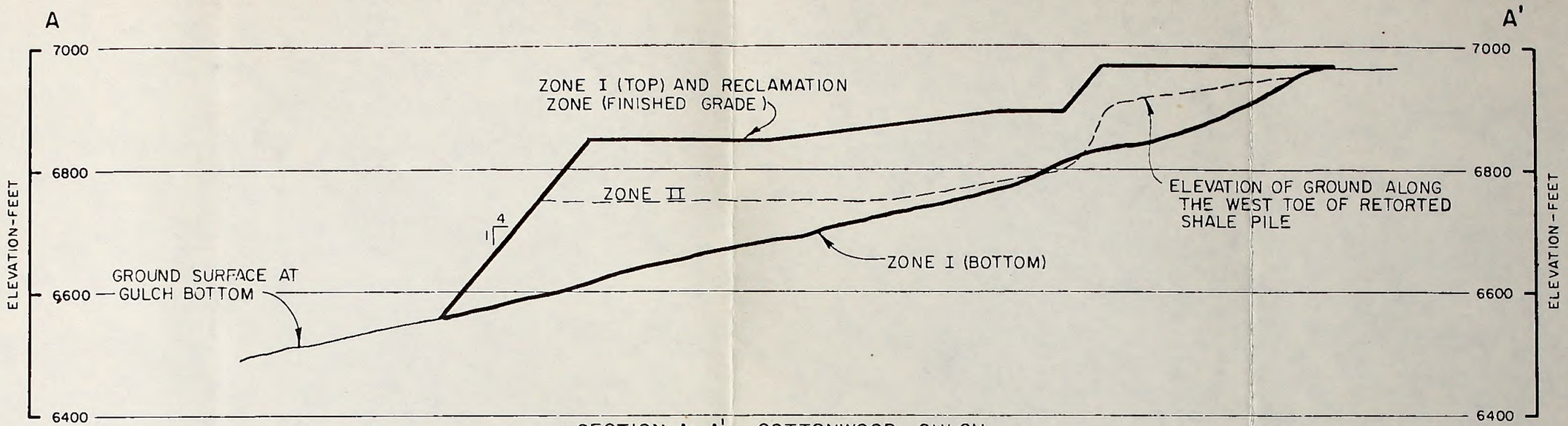
SCALE · HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'

NOTES:

1. SEE FIGURE 3 FOR SECTION LOCATION.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

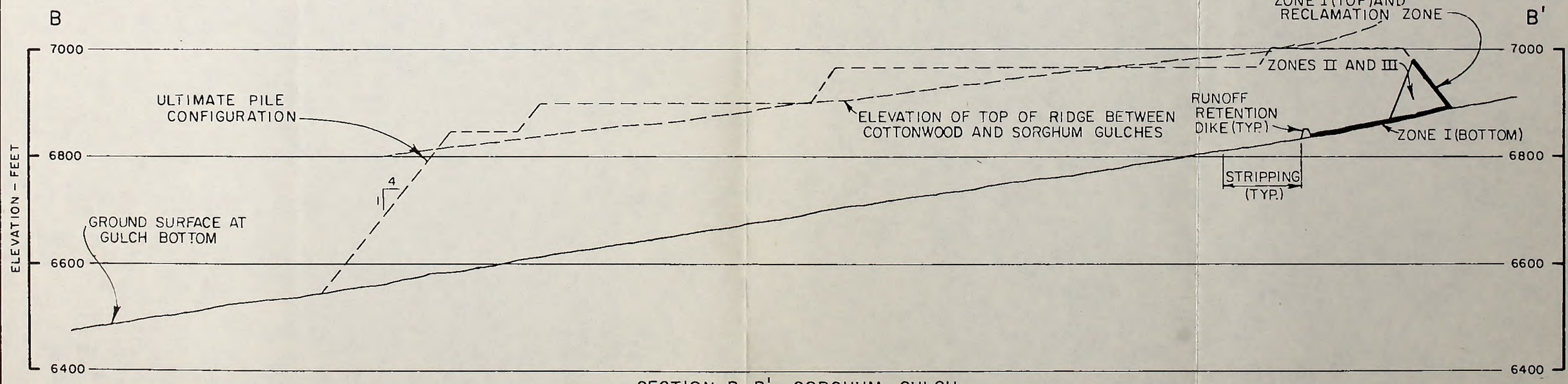
Job No. : 21120 – 19605	DISPOSAL AREA SECTIONS YEAR 5
Prepared by: K.E.A	
Date: 8/2/83	

FIG. 9



SECTION A-A' – COTTONWOOD GULCH

SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'



SECTION B-B' – SORGHUM GULCH

SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'

NOTES:

1. SEE FIGURE 4 FOR SECTION LOCATIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

Job No. : 21120-19605	DISPOSAL AREA SECTIONS
Prepared by: K.E.A.	YEAR 12
Date: 8/2/83	

FIG. 10

Cathedral
Bluffs Shale Oil Company
P.O. Box 2687, Grand Junction, Colorado 81502-2687

RECEIVED
MAY 24 1984
CRAIG DISTRICT OFFICE
OIL SHALE PROJECTS OFFICE

May 22, 1984

Mr. Robert L. Elderkin, Jr.
Oil Shale Project Manager
USDI, Bureau of Land Management
Oil Shale Project Office
P.O. Box 580
Grand Junction, CO 81502

Subject: OSPO Request for Woodward-Clyde Report and
Status of Mined Land Reclamation Amendment

Dear Mr. Elderkin:

In response to your comments on Cathedral Bluffs' draft Detailed Development Plan (DDP), please find enclosed a copy of the Woodward-Clyde Consultants report for CB titled "Preliminary Geotechnical, Hydrological and Environmental Services, Retorted Shale Disposal Area, Cathedral Bluffs Shale Oil Project, C-b Tract, Rio Blanco County, Colorado, Contract CB-13-83".

Your request for the State Mined Land Reclamation Amendment (MLRA) is premature as we have not yet completed the test work. The CB submittal to MLRB is planned for August-September 1984. At that time a copy will be sent to your office. The DDP and MLRA will be compatible.

If you have any questions, please contact us.

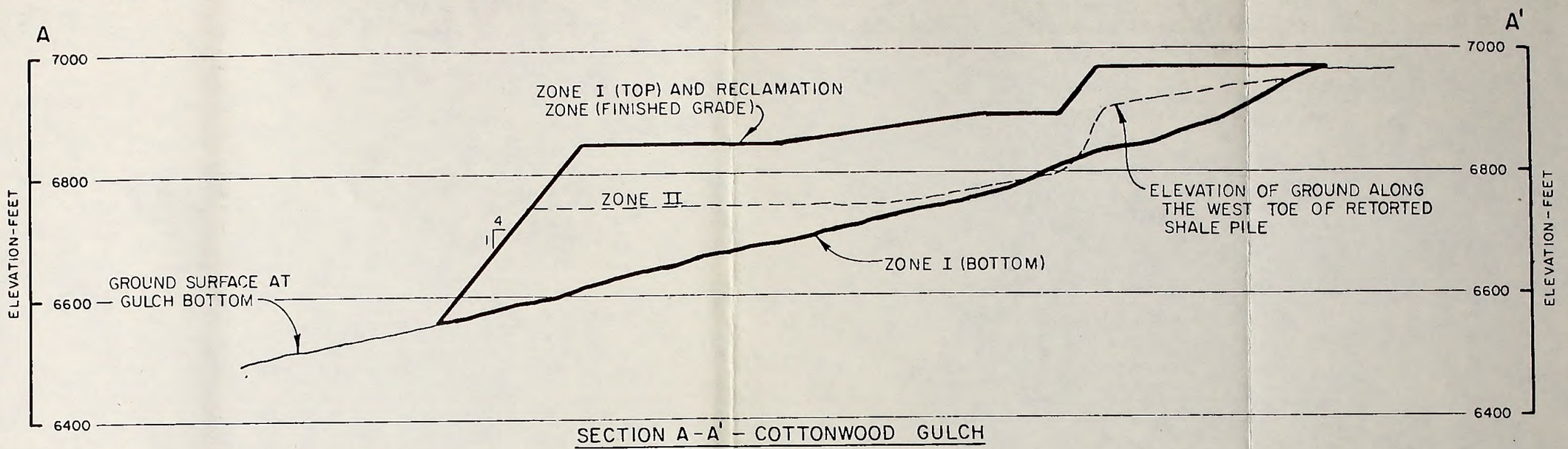
Very truly yours,

CATHEDRAL BLUFFS SHALE OIL COMPANY

R. E. Thomason
Vice President
Regulatory Affairs

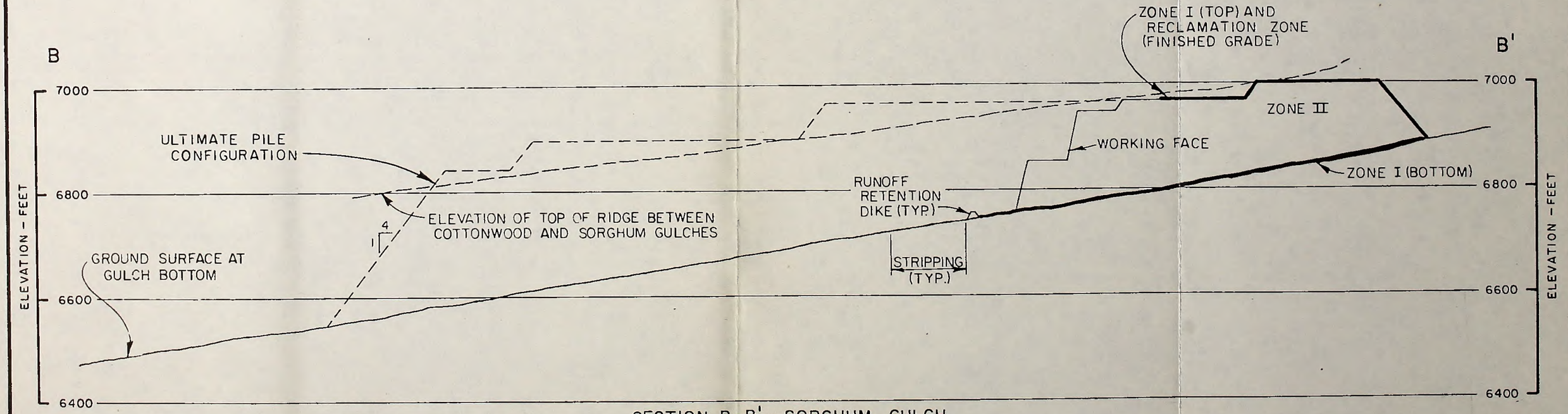
RET/EBB:pmr

Encl.



SECTION A-A' – COTTONWOOD GULCH

SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'



SECTION B-B' – SORGHUM GULCH

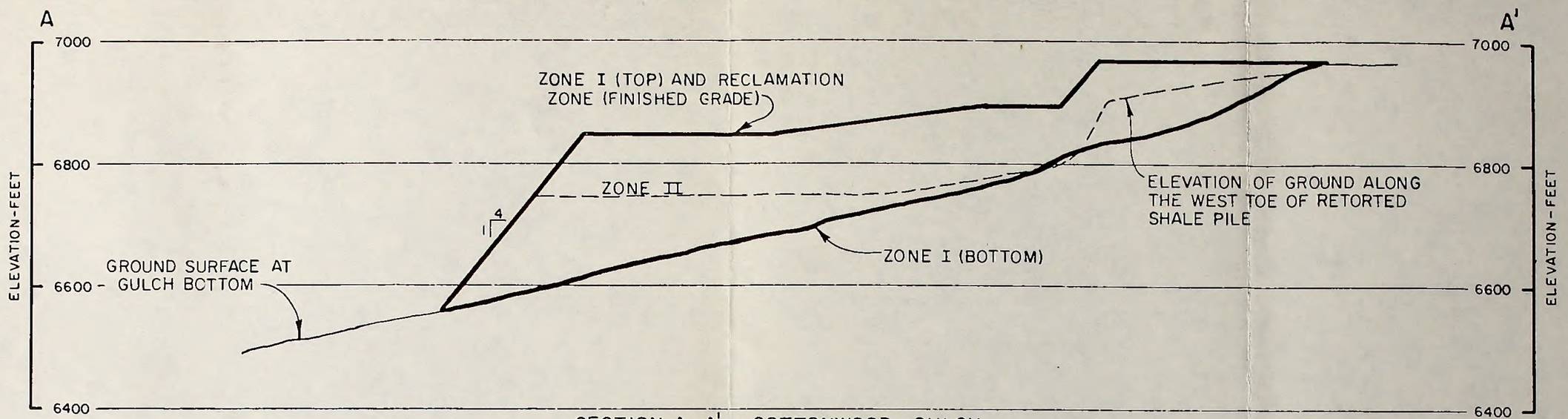
SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'

NOTES:

1. SEE FIGURE 5 FOR SECTION LOCATIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

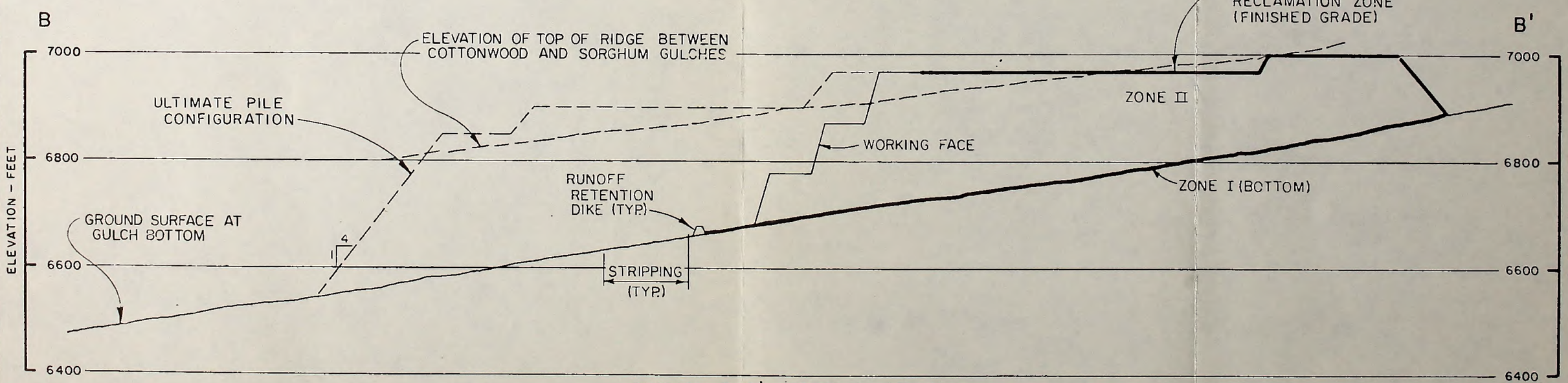
Job No. : 21120-19605	DISPOSAL AREA SECTIONS
Prepared by: K.E.A.	YEAR 20
Date: 8/2/83	

FIG. 11



SECTION A-A' – COTTONWOOD GULCH

SCALE: HORIZONTAL 1"= 1000'
VERTICAL 1"= 200'



SECTION B-B' – SORGHUM GULCH

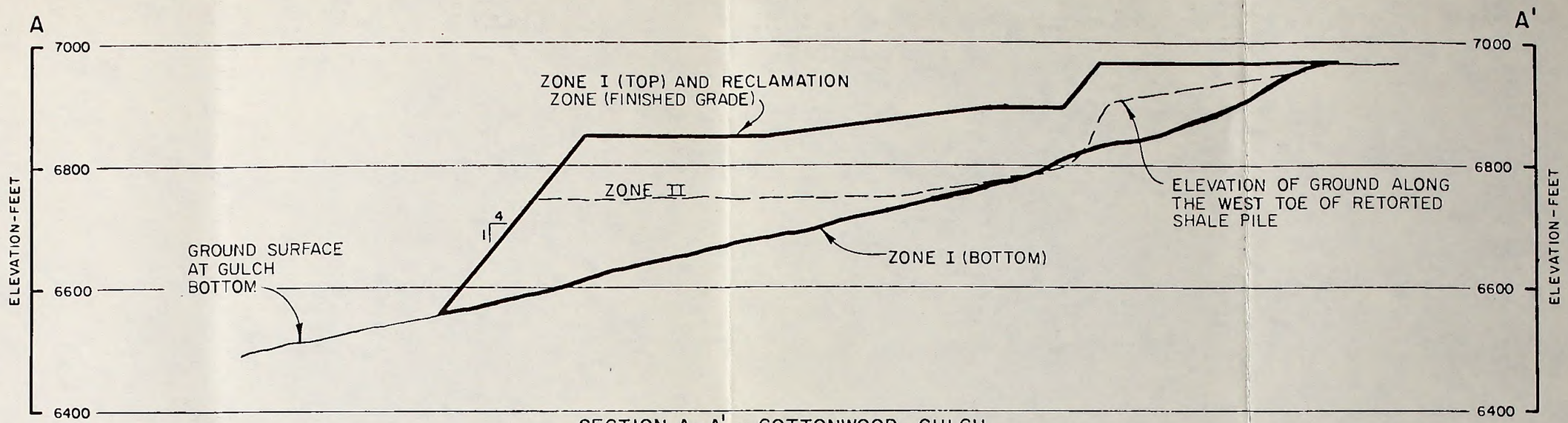
SCALE: HORIZONTAL 1"= 1000'
VERTICAL 1"= 200'

NOTES:

1. SEE FIGURE 6 FOR SECTION LOCATIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

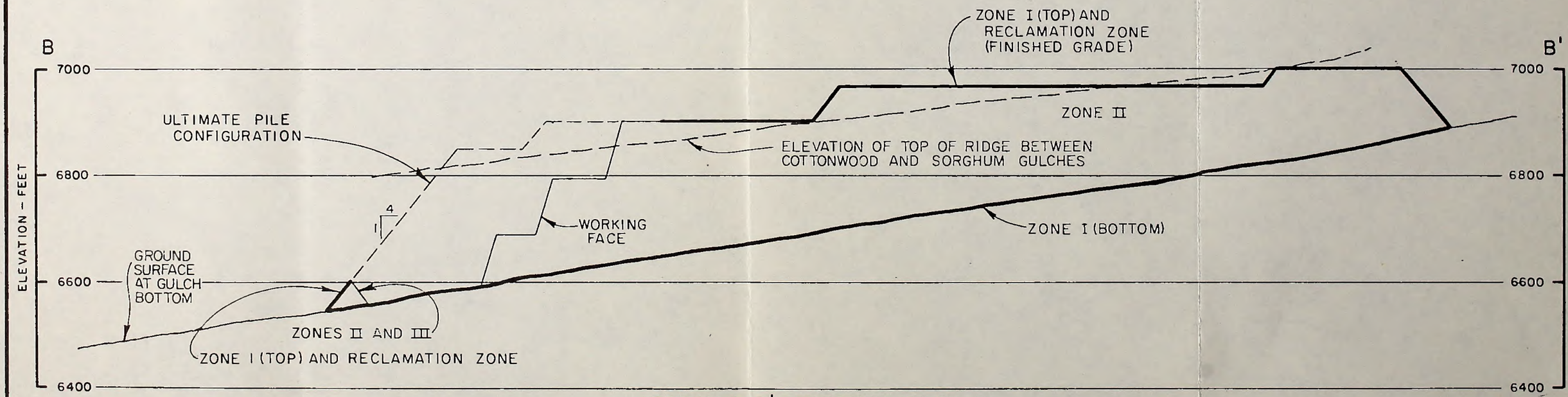
Job No. : 21120-19605	DISPOSAL AREA SECTIONS YEAR 30
Prepared by: K.E.A.	
Date: 8/2/83	

FIG. 12



SECTION A-A' – COTTONWOOD GULCH

SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'



SECTION B-B' – SORGHUM GULCH

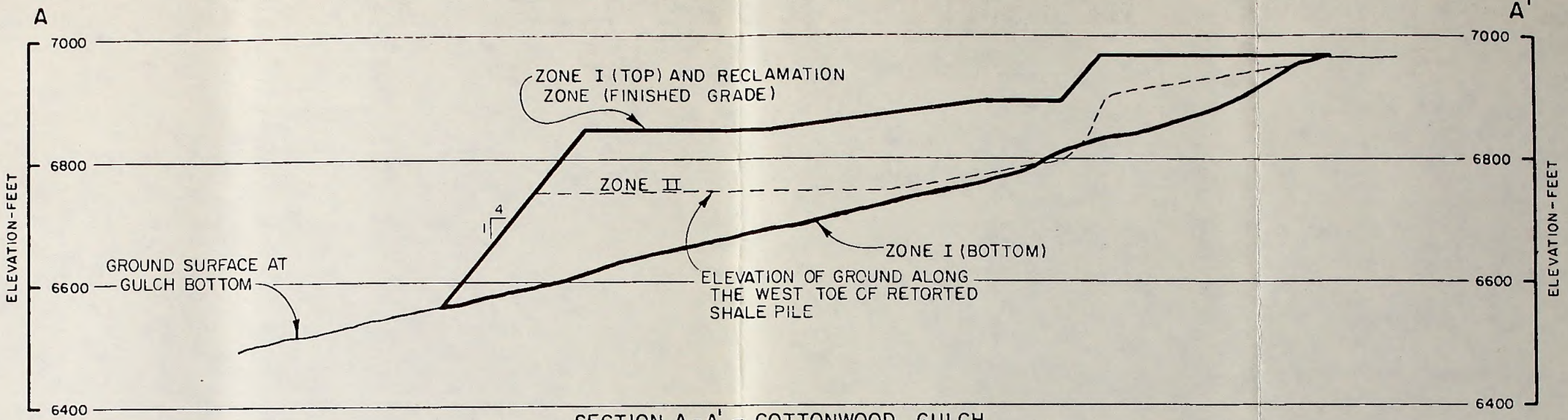
SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'

NOTES:

1. SEE FIGURE 7 FOR SECTION LOCATIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

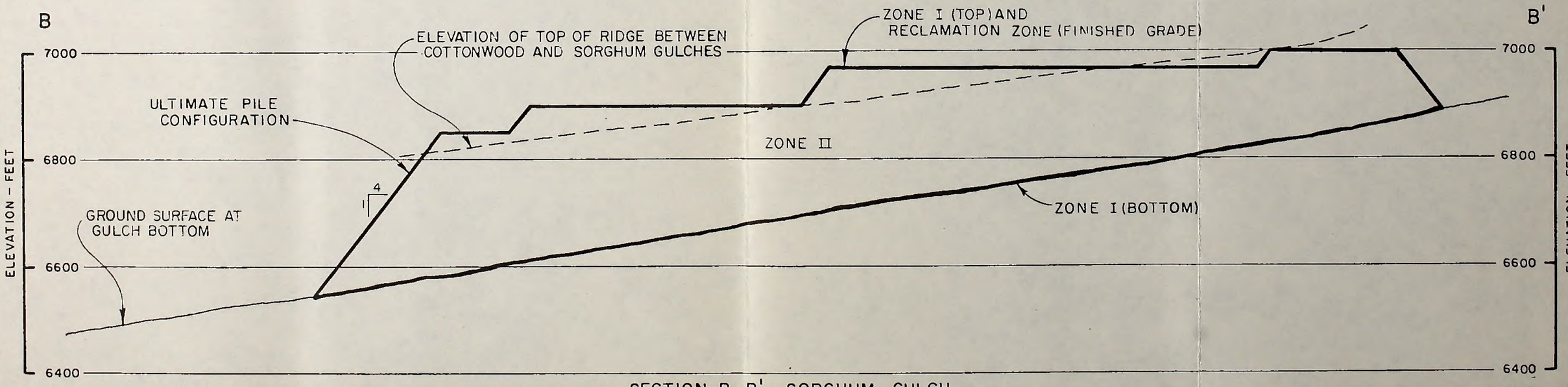
Job No. : 21120-19605	DISPOSAL AREA SECTIONS
Prepared by: K.E.A.	YEAR 40
Date: 8/2/83	

FIG. 13



SECTION A-A' – COTTONWOOD GULCH

SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'



SECTION B-B' – SORGHUM GULCH

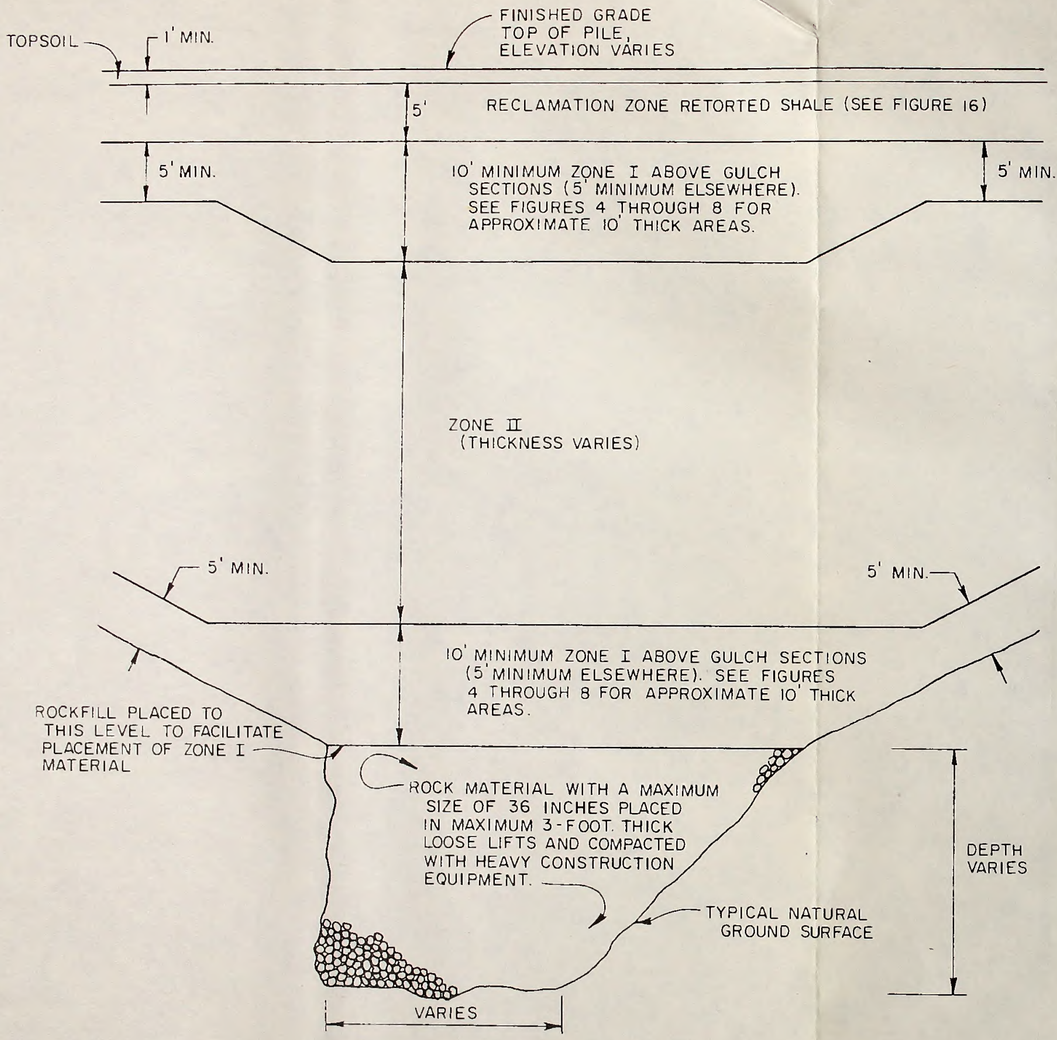
SCALE: HORIZONTAL 1" = 1000'
VERTICAL 1" = 200'

NOTES:

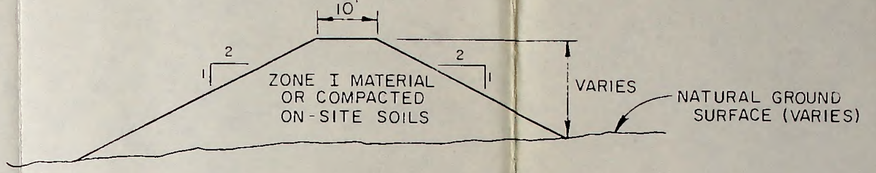
1. SEE FIGURE 8 FOR SECTION LOCATIONS.
2. SEE FIGURE 16 FOR ZONE DESCRIPTIONS AND DETAILS.

Job No. : 21120-19605	DISPOSAL AREA SECTIONS
Prepared by: K. E. A.	YEAR 45
Date: 8/2/83	

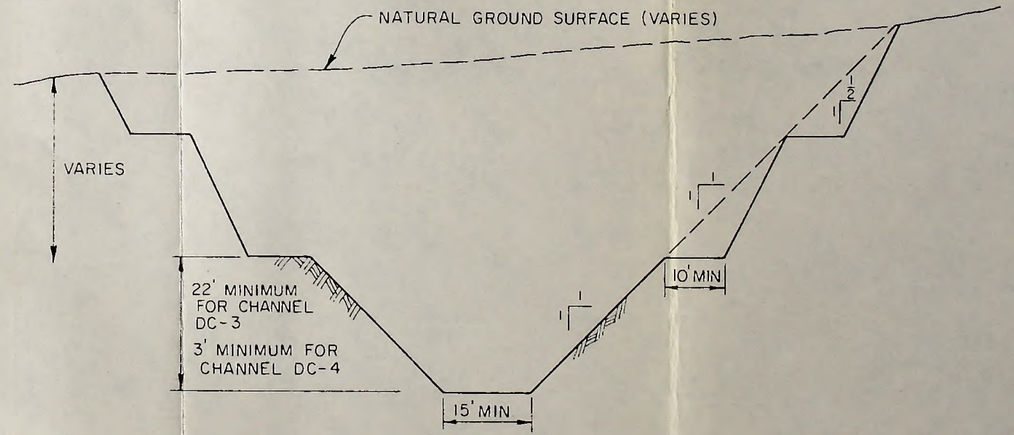
FIG. 14


TOPSOIL
1' MIN.
FINISHED GRADE
TOP OF PILE,
ELEVATION VARIES
5'
RECLAMATION ZONE RETORTED SHALE (SEE FIGURE 16)
5' MIN.
10' MINIMUM ZONE I ABOVE GULCH SECTIONS (5' MINIMUM ELSEWHERE). SEE FIGURES 4 THROUGH 8 FOR APPROXIMATE 10' THICK AREAS.
5' MIN.
ZONE II
(THICKNESS VARIES)
5' MIN.
5' MIN.
10' MINIMUM ZONE I ABOVE GULCH SECTIONS (5' MINIMUM ELSEWHERE). SEE FIGURES 4 THROUGH 8 FOR APPROXIMATE 10' THICK AREAS.
ROCKFILL PLACED TO THIS LEVEL TO FACILITATE PLACEMENT OF ZONE I MATERIAL
ROCK MATERIAL WITH A MAXIMUM SIZE OF 36 INCHES PLACED IN MAXIMUM 3-FOOT THICK LOOSE LIFTS AND COMPACTED WITH HEAVY CONSTRUCTION EQUIPMENT.
TYPICAL NATURAL GROUND SURFACE
DEPTH VARIES
VARIES

SECTION C-C'
PROFILE ABOVE TYPICAL GULCH SECTION
SEE FIGURES 5 THROUGH 8 FOR SECTION LOCATION



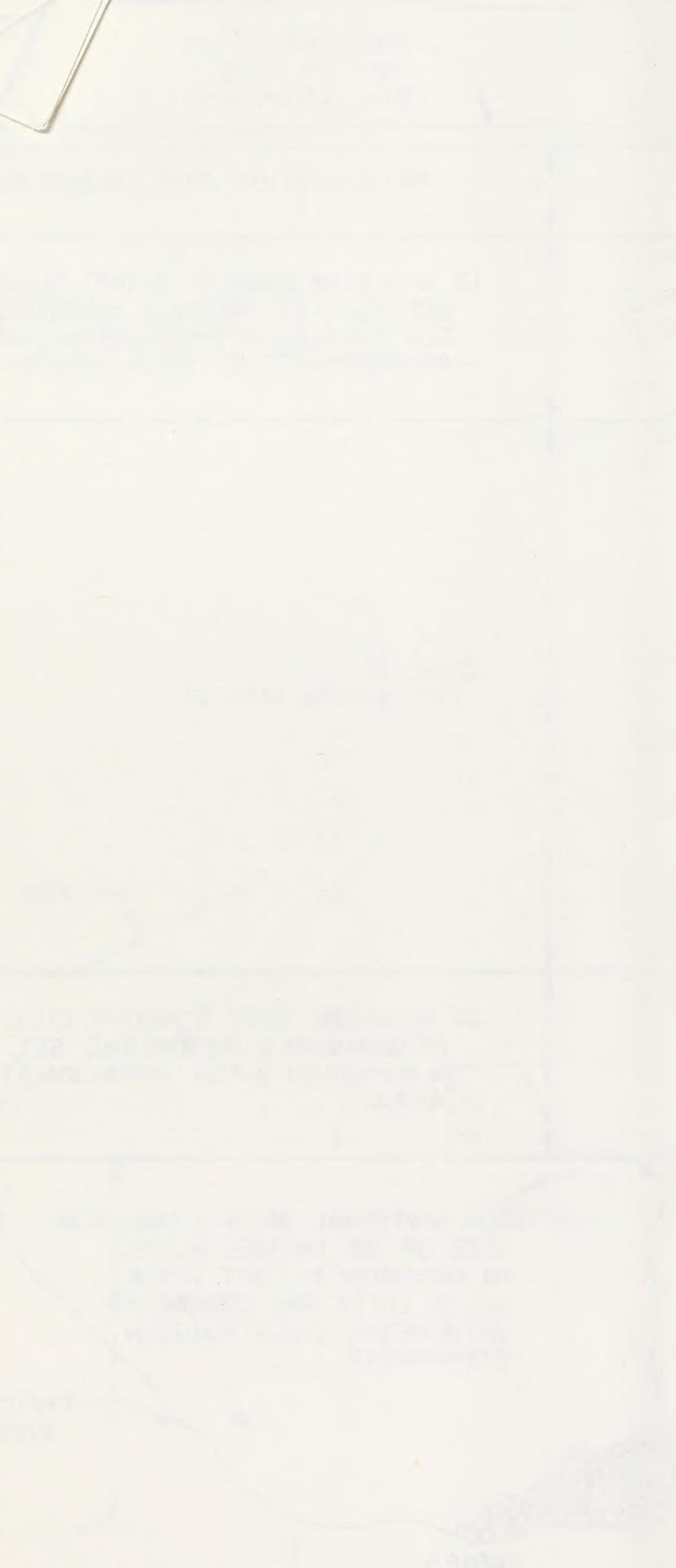
SECTION D-D'
TYPICAL RUNOFF RETENTION DIKE SECTION
SEE FIGURES 4 THROUGH 7 FOR SECTION LOCATION

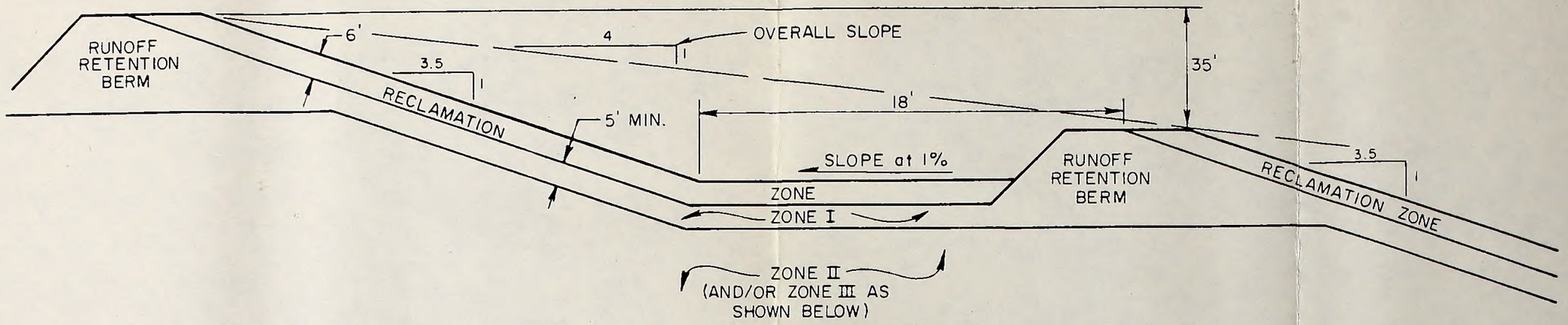


SECTION E-E'
TYPICAL WATER DIVERSION CHANNEL SECTION
SEE FIGURES 4 THROUGH 8 FOR SECTION LOCATIONS

Job No 21120-19605	TYPICAL SECTIONS
Prepared by: K.E.A.	
Date 8/2/83	

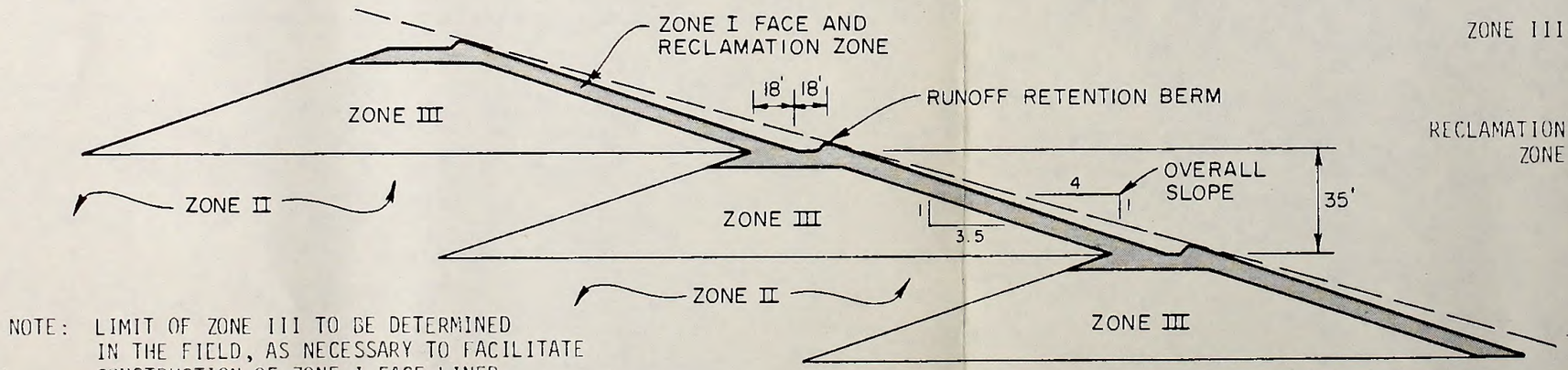
FIG. 15





TYPICAL BENCH DETAIL

NOT TO SCALE



NOTE: LIMIT OF ZONE III TO BE DETERMINED IN THE FIELD, AS NECESSARY TO FACILITATE CONSTRUCTION OF ZONE I FACE LINER.

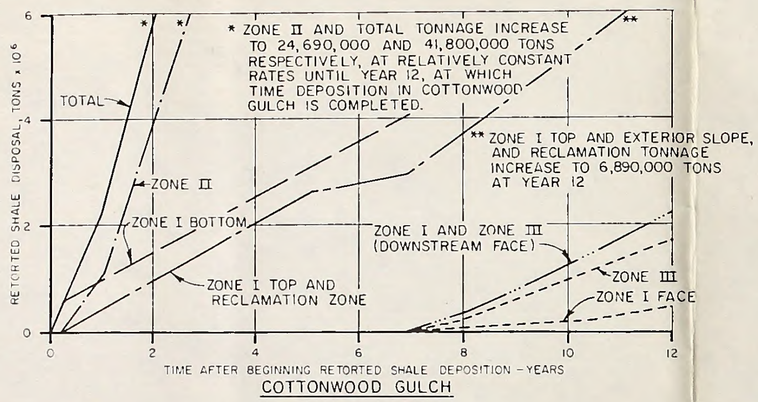
ZONE I FACE DETAIL

NOT TO SCALE

	DESCRIPTION OF MATERIALS
ZONE I	RETORTED SHALE, PLACED IN 8-INCH THICK MAXIMUM LOOSE LIFTS, AT THE MOISTURE CONTENT OPTIMUM FOR COMPACTION AND COMPACTED TO 100 MAXIMUM DENSITY (ASTM D 1557).
ZONE II	RETORTED SHALE, NO ADDITIONAL MOISTURE OR COMPACTION REQUIRED.
ZONE III	RETORTED SHALE, COMPACTED BY CONSTRUCTION EQUIPMENT ONLY AS NEEDED TO FACILITATE CONSTRUCTION OF ZONE I FACE LINER.
RECLAMATION ZONE	5 FEET OF UNCOMPACTED RETORTED SHALE COVERED WITH A MINIMUM OF 1-FOOT OF TOPSOIL.

Job No. : 21120-19605	BENCH AND FACE DETAILS
Prepared by: K.E.A.	
Date: 4/22/83	

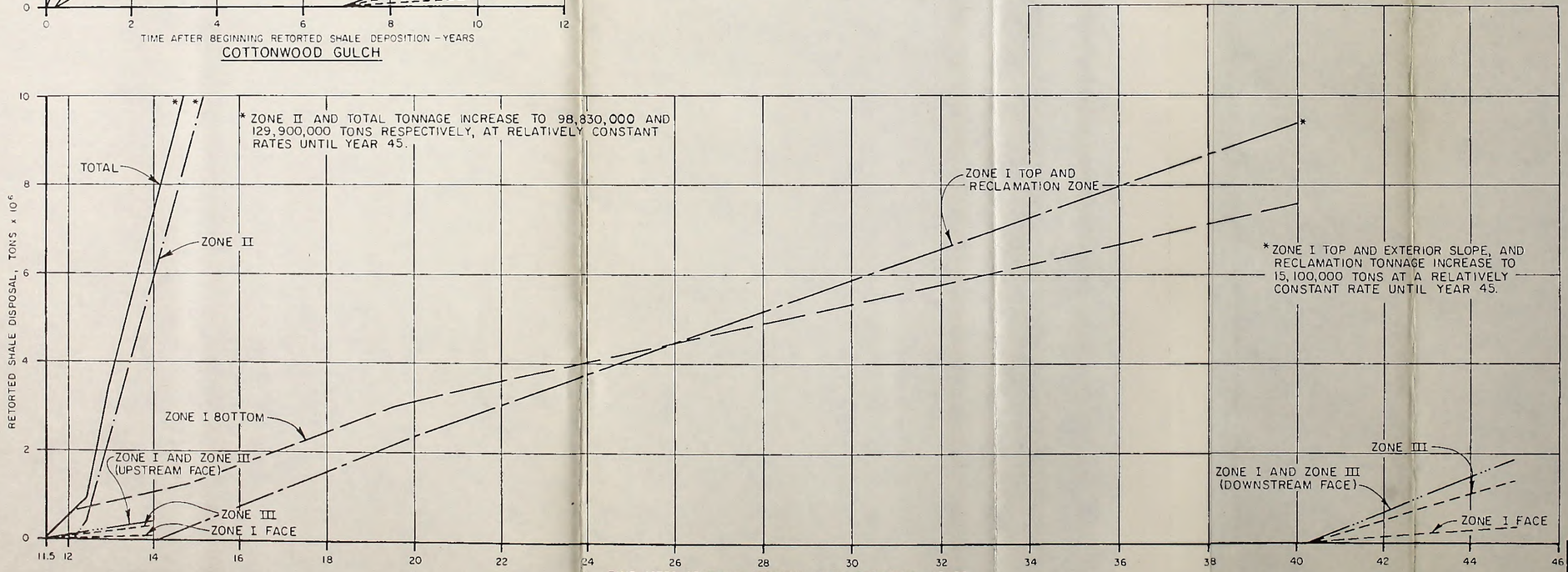
FIG. 16


* ZONE II AND TOTAL TONNAGE INCREASE TO 24,690,000 AND 41,800,000 TONS RESPECTIVELY, AT RELATIVELY CONSTANT RATES UNTIL YEAR 12, AT WHICH TIME DEPOSITION IN COTTONWOOD GULCH IS COMPLETED.
** ZONE I TOP AND EXTERIOR SLOPE, AND RECLAMATION TONNAGE INCREASE TO 6,890,000 TONS AT YEAR 12
TOTAL
ZONE II
ZONE I BOTTOM
ZONE I TOP AND RECLAMATION ZONE
ZONE I AND ZONE III (DOWNSTREAM FACE)
ZONE III
ZONE I FACE
RETORTED SHALE DISPOSAL, TONS x 10⁶
TIME AFTER BEGINNING RETORTED SHALE DEPOSITION - YEARS
0
2
4
6
8
10
12

COTTONWOOD GULCH

NOTES:

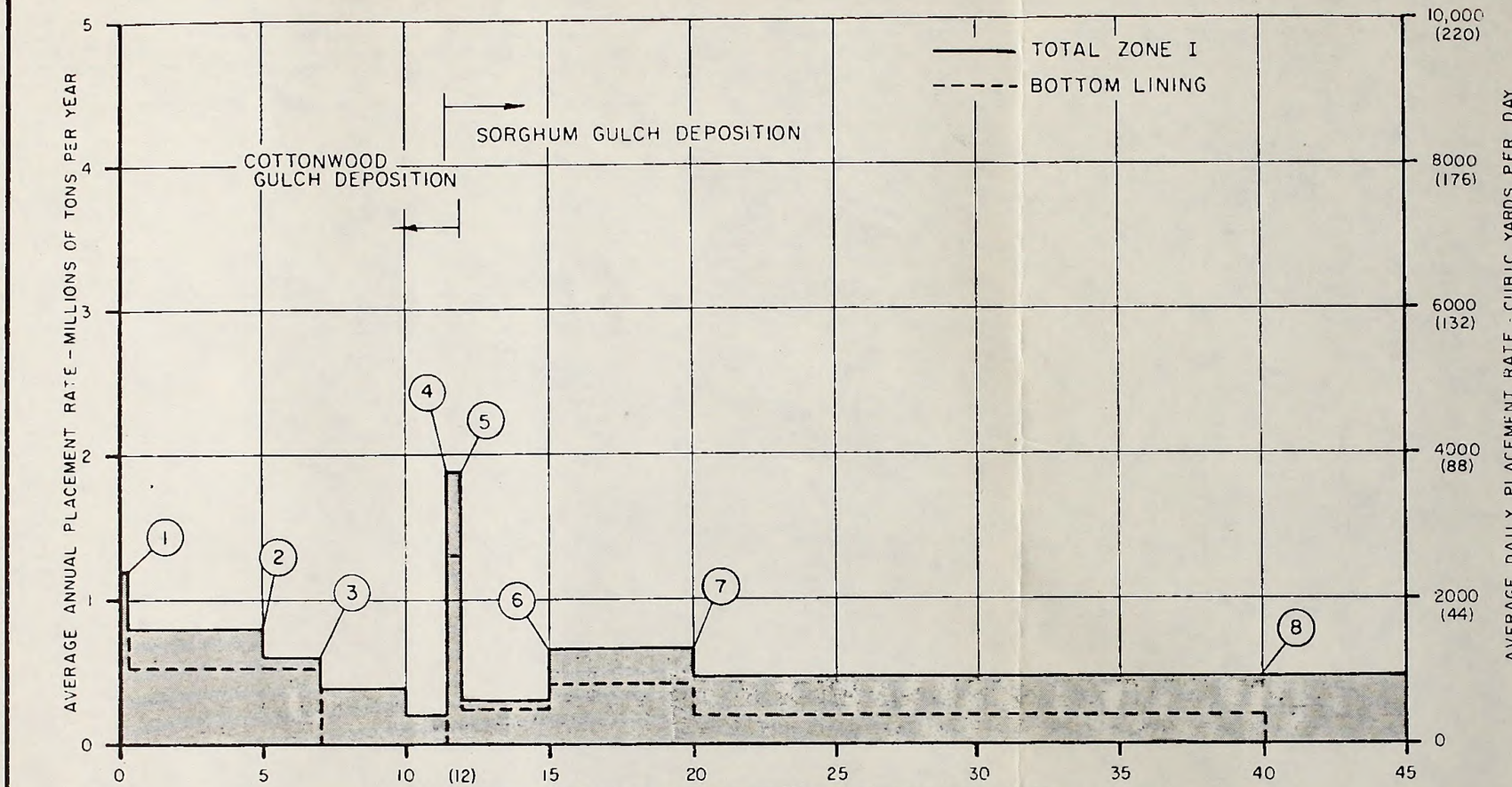
1. ZONE I BOTTOM REFERS TO COMPACTED RETORTED SHALE PLACED OVER STRIPPED NATURAL GROUND AND BENEATH ZONE II MATERIAL.
2. ZONE I TOP REFERS TO COMPACTED RETORTED SHALE PLACED ABOVE ZONE II.
3. ZONE I FACE REFERS TO COMPACTED RETORTED SHALE PLACED ON SLOPE FACES.
4. ZONE II REFERS TO UNCOMPACTED RETORTED SHALE PLACED IN DISPOSAL PILE.
5. ZONE III FACE REFERS TO RETORTED SHALE COMPACTED BY CONSTRUCTION EQUIPMENT ONLY AS NEEDED TO FACILITATE CONSTRUCTION OF ZONE I MATERIALS.
6. RECLAMATION ZONE REFERS TO RETORTED SHALE PLACED OVER ZONE I TOP AND FACE MATERIAL.
7. SEE FIGURE 16 FOR ZONE DESCRIPTION AND DETAILS.
8. THE TIMETABLE SHOWN ON THIS FIGURE IS BASED ON THE ASSUMPTIONS DISCUSSED IN THIS REPORT.
9. SEE FIGURES 3 THROUGH 14 FOR CORRESPONDING DISPOSAL AREA PLANS AND SECTIONS.



SORGHUM GULCH

Job No. : 21120-19605	DISPOSAL TIMETABLE
Prepared by: R.M.D.	
Date: 8/1/83	

FIG. 17



(1) 3 MONTHS – PREPARE UPSTREAM END OF COTTONWOOD GULCH

(2) YEAR 5 - TOP LINING REACHES CREST OF COMPLETED ZONE II

(3) YEAR 7 - BOTTOM LINING REACHES DOWNSTREAM TOE, FACE CONSTRUCTION BEGINS

(4) YEAR 11.5 – PREPARE UPSTREAM END OF SORGHUM GULCH

(5) YEAR 12 - COMPLETE COTTONWOOD GULCH, CONTINUE UPSTREAM FACE AND BOTTOM LINING OF SORGHUM GULCH

(6) YEAR 15 - COMPLETE UPSTREAM FACE, START TOP LINING

(7) YEAR 20 - TOP LINING REACHES CREST OF COMPLETED ZONE II

(8) YEAR 40 - BOTTOM LINING REACHES DOWNSTREAM TOE, DOWNSTREAM FACE CONSTRUCTION BEGINS

NOTES:

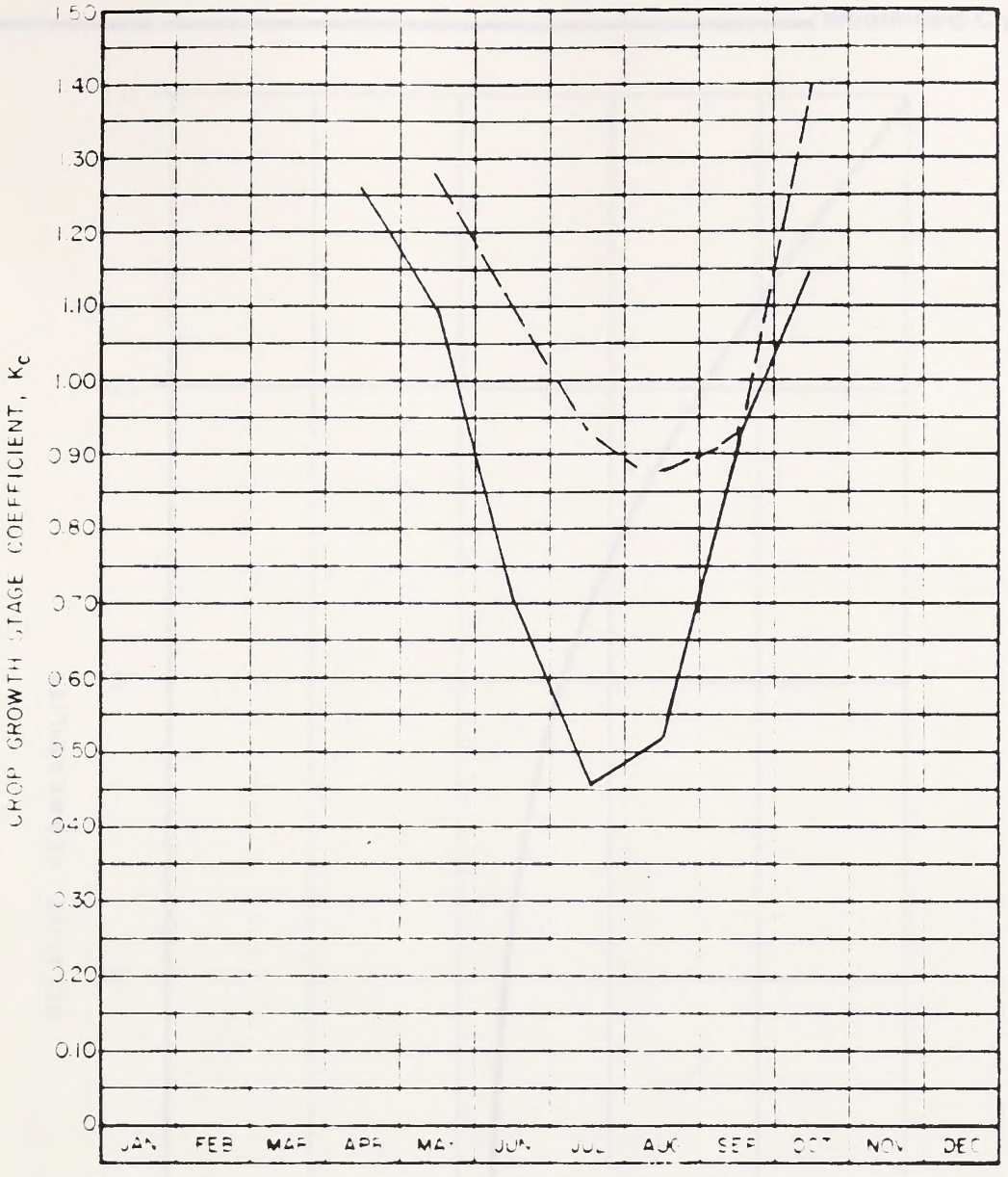
1. SEE THE TEXT OF THIS REPORT FOR ASSUMPTIONS AND PLACEMENT METHODS UPON WHICH THE ESTIMATED ZONE I DEPOSITION RATES ARE BASED.

2. THE AVERAGE DAILY PLACEMENT RATE ASSUMES MATERIAL PLACED 365 DAYS PER YEAR.

3. THE AVERAGE DAILY WATER REQUIREMENT ASSUMES THE RETORTED SHALE LEAVES THE WETTER FACILITY AT A MOISTURE CONTENT OF 16 PERCENT (BY WEIGHT), DRIES TO A MOISTURE CONTENT OF 14 PERCENT BEFORE BEING USED AS ZONE I MATERIAL, AND IS WETTED TO A MOISTURE CONTENT OF 21 PERCENT, THE OPTIMUM MOISTURE CONTENT FOR COMPACTION, WHEN USED AS ZONE I MATERIAL. IT ALSO ASSUMES ZONE I MATERIAL IS PLACED 365 DAYS PER YEAR, 24 HOURS PER DAY. THE ESTIMATE DOES NOT INCLUDE THE 16 PERCENT MOISTURE ADDED TO THE RETORTED SHALE IN THE WETTER FACILITY.

Job No. : 21120-19605	ZONE I DEPOSITION RATES
Prepared by: K E A.	
Date: 8/3/83	

FIG. 18



L E G E N D

——— GROWTH STAGE CURVE FROM UOC TEST PLOTS

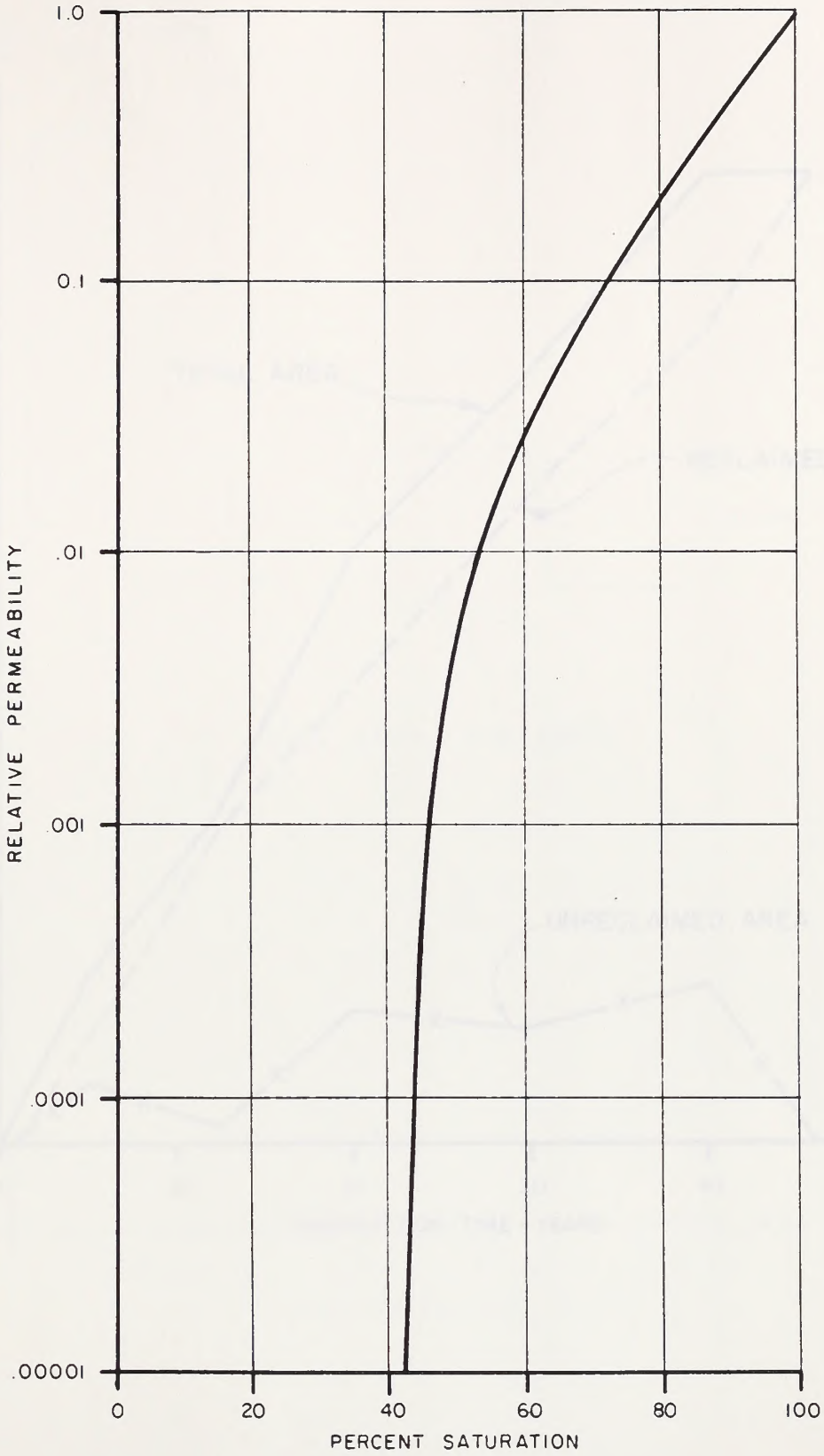
– – – – GROWTH STAGE CURVE FOR DROUGHT RESISTANT GRASSES (O'NEILL, POCHOP AND BORRELLI, 1979)

NOTE:

1. GROWTH STAGE CURVE FOR UOC PLOTS ESTIMATED FROM SOIL MOISTURE DATA COLLECTED BY UOC (BERG AND OTHERS, 1978; 1979; HARBERT AND BERG, 1979; KILKELLY, 1981).

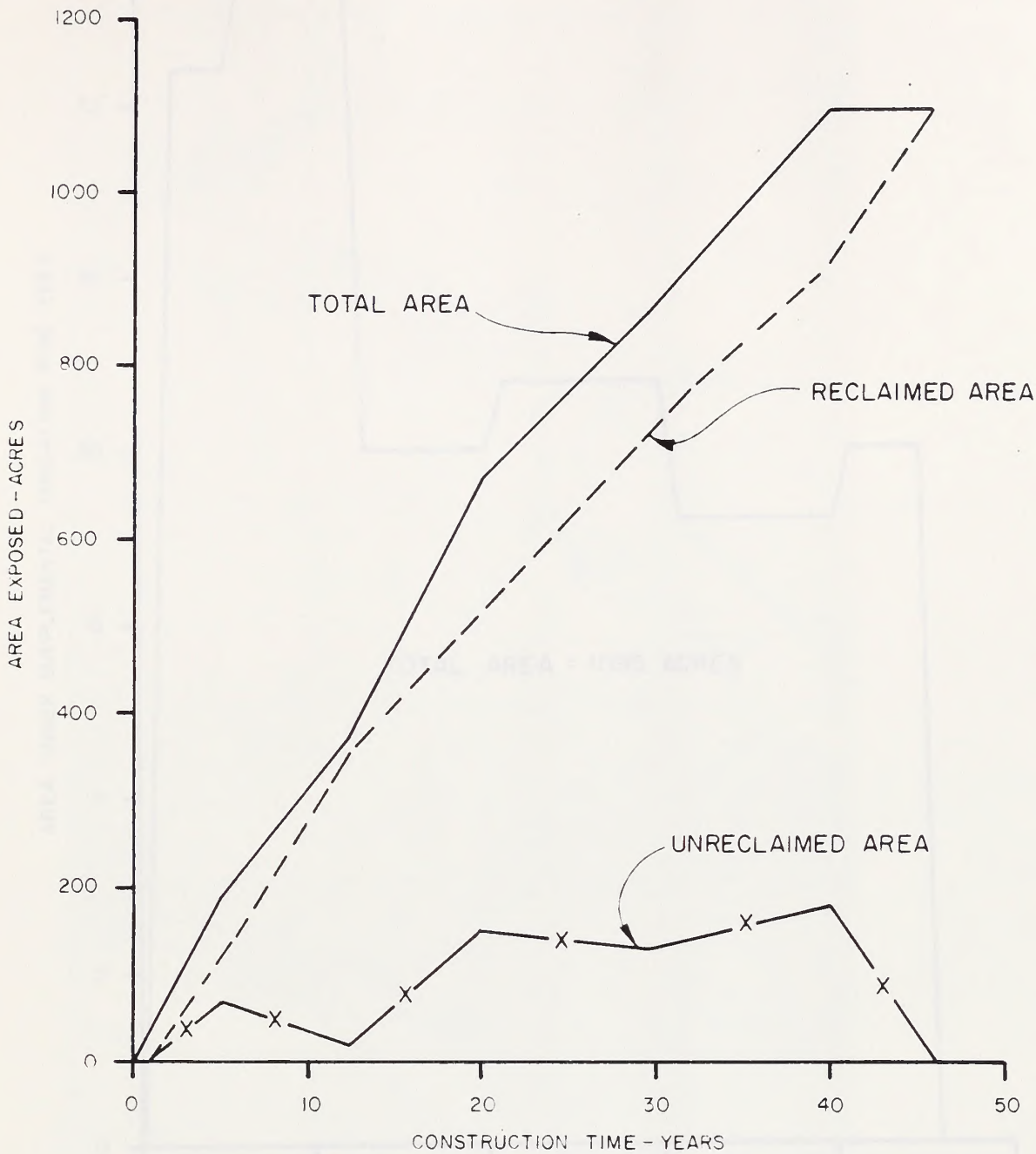
Job No. : 21120-19605	VEGETATION GROWTH STAGE COEFFICIENTS
Prepared by: J. R. K.	
Date: 4/28/83	

FIG. 19



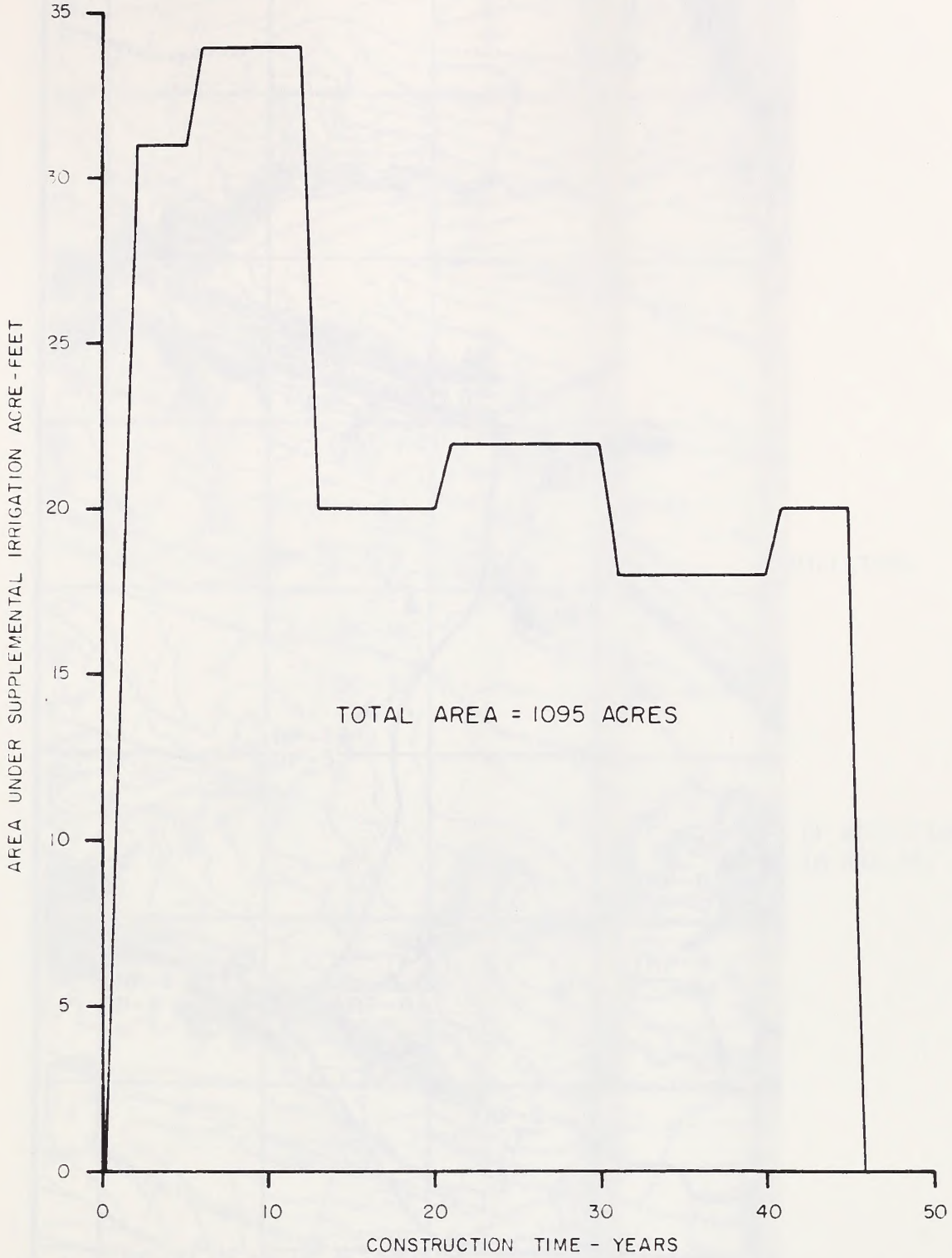
SOURCE: UOC, 1982

Job No. : 21120-19605	RELATIVE PERMEABILITY OF WHEEL COMPACTED RETORTED SHALE
Prepared by : J. R K	
Date : 4/28/83	



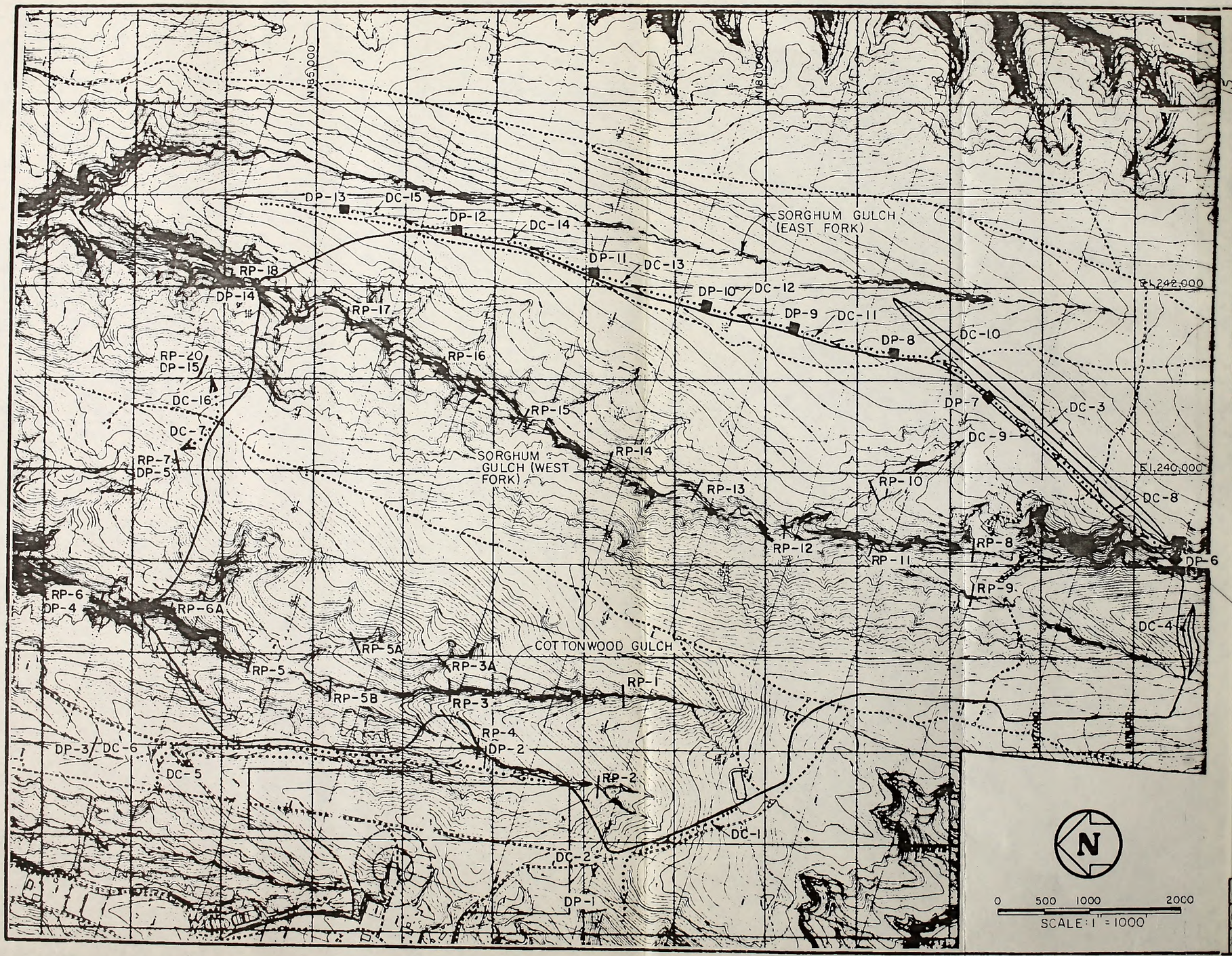
Job No. : 21120 - 19605	RETORTED SHALE PILE AREA DURING CONSTRUCTION
Prepared by : R.B.M.	
Date : 9/16/83	

FIG. 21



Job No. : 21120 - 19605	IRRIGATED AREAS
Prepared by: R.B.M.	
Date: 9/15/83	

FIG. 22



LEGEND

DP-1 ■
DP-2 — } DETENTION POND

DC-6 → DIVERSION CHANNEL AND FLOW DIRECTION

RP-5 — RETENTION POND

OUTLINE OF FILL

NOTE:

1. FOR APPROXIMATE TIME SEQUENCING OF RETENTION AND DETENTION PONDS, SEE TABLES 18 AND 20, RESPECTIVELY.

FIGURE 6.2-2

Job No 21120-19605	SURFACE WATER CONTROL SYSTEM
Prepared by: R.B.M	STRUCTURE LOCATION MAP
Date: 5/4/83	

FIG. 23

LEGEND

STUDY AREA BOUNDARY

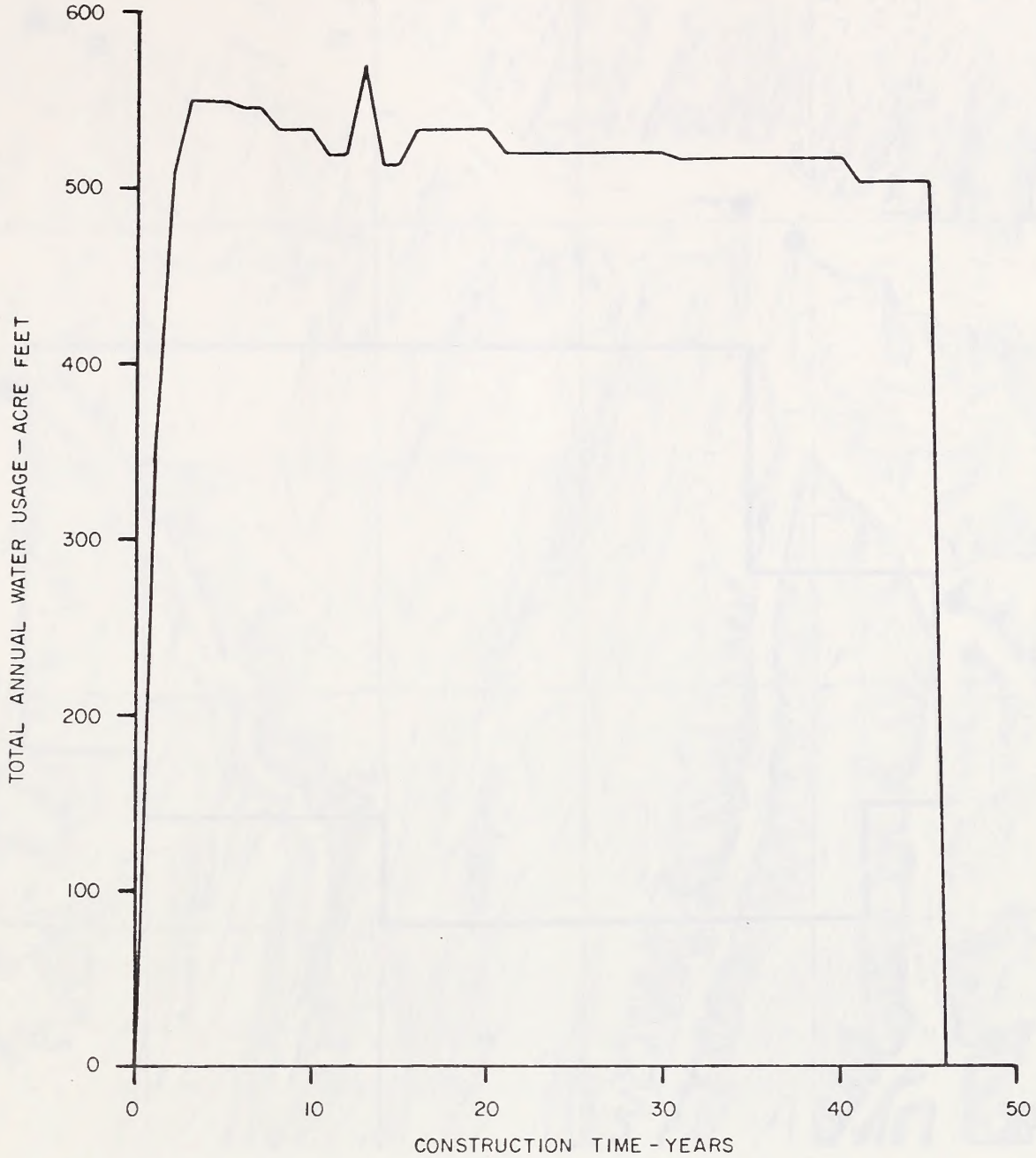
SOIL MAP UNIT BOUNDARY

SOIL MAP UNITS

SYMBOL	TOPSOIL STRIPPING DEPTH (FT)	SOIL MAP UNIT NAME
33	5.0	FORELLE LOAM, 3 TO 8 SLOPES
64	2.5	PICEANCE FINE SANDY LOAM, 5 TO 15 SLOPES
70	0.5 TO 1.3	REDCREEK-RENTSAC COMPLEX, 5 TO 30 SLOPES
73	0.5	RENTSAC CHANNERY LOAM, 5 TO 50 SLOPES

Job No.: 21120-19605	TOPSOIL STRIPPING MAP
Prepared by: C S N	
Date: 4/25/83	

FIG. 24



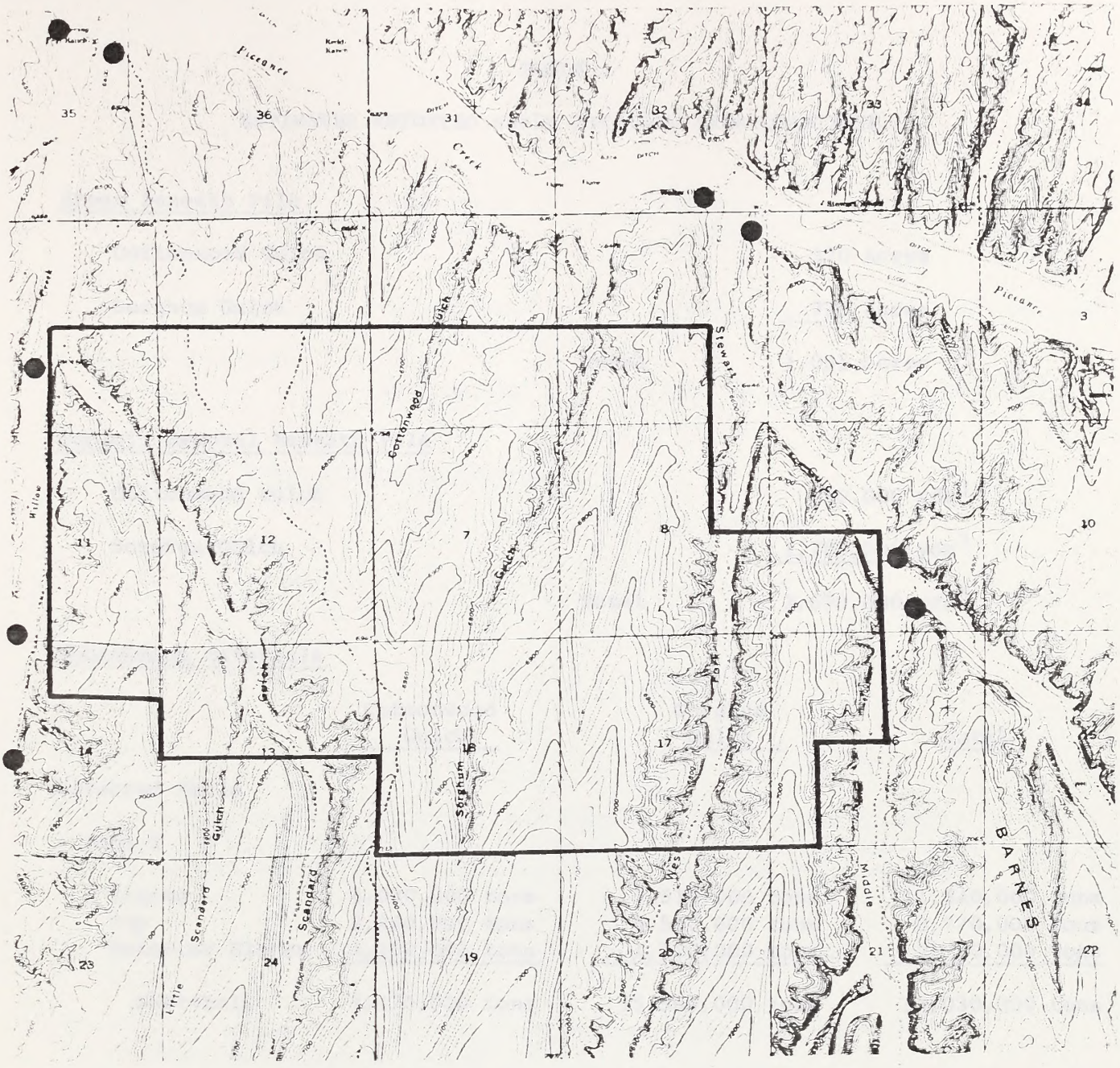
NOTES:

1. TOTAL ANNUAL WATER USAGE INCLUDES WATER TO THE WETTER, WATER FOR ZONE I COMPACTION, WATER FOR DUST SUPRESSION AND WATER FOR IRRIGATION.

2. ONE ACRE-FOOT OF WATER PER YEAR IS APPROXIMATELY EQUIVALENT TO 0.62 GPM.

Job No. : 21120-19605	ANNUAL WATER REQUIREMENT FOR RETORTED SHALE DISPOSAL PILE CONSTRUCTION AND RECLAMATION
Prepared by: R.B.M.	
Date: 9/15/83	

FIG. 25



0 2000 4000 8000

SCALE IN FEET

LEGEND

● SPRINGS AND SEEPS

— APPROXIMATE LEASE BOUNDARY

SOURCE: 1981 CATHEDRAL BLUFFS ANNUAL REPORT, ENVIRONMENTAL ANALYSIS.

Job No.: 21120-19605	LOCATION MAP SPRINGS AND SEEPS
Prepared by: R.B.M.	
Date: 9/23/83	

FIG. 26

TABLE 1

ESTIMATED RETORTED SHALE DISPOSAL AREA QUANTITIES

Areas Beneath Pile

Cottonwood Gulch		370 Acres
Sorghum Gulch		725 Acres
	Total	1,095 Acres

Topsoil Removal Beneath Pile

Cottonwood Gulch		890,000 yds^3
Sorghum Gulch		1,780,000 yds^3
	Total	2,670,000 yds^3

Embankment Materials

	Cottonwood Gulch	Sorghum Gulch	Total
Retorted Shale			
Zone I			
Lining	4,030,000 tons	7,510,000 tons	11,540,000 tons
Top	2,240,000 tons	6,530,000 tons	8,770,000 tons
Exterior Slopes	1,200,000 tons	1,520,000 tons	2,720,000 tons
Subtotals	7,470,000 tons	15,560,000 tons	23,030,000 tons
Zone II	24,690,000 tons	98,830,000 tons	123,520,000 tons
Zone III	6,190,000 tons	8,460,000 tons	14,650,000 tons
Reclamation Zone	3,450,000 tons	7,050,000 tons	10,500,000 tons
Totals	41,800,000 tons	129,900,000 tons	171,700,000 tons

TABLE 1
(Continued)

	Cottonwood Gulch	Sorghum Gulch	Total
Rockfill (steep gulches)	60,000 yds^3	63,000 yds^3	123,000 yds^3
Reclamation Zone Topsoil	600,000 yds^3	1,167,000 yds^3	1,767,000 yds^3
Sorghum Gulch Water Diversion Channels			
Excavation		1,050,000 yds^3	

Notes:

(1) The quantities for Cottonwood and Sorghum Gulches refer to those west and east, respectively, of the crest of the ridge separating Cottonwood and Sorghum Gulches within the retorted shale disposal pile area.

(2) Retorted shale embankment material types are as discussed on Figure 15.

(3) Retorted shale disposal area configurations and sections are provided on Figures 3 through 14.

TABLE 2

ESTIMATED PRECIPITATION AT RETORTED SHALE PILE[1)]

Calendar Sequence		Monthly Precipitation (inches)												
Year	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1951	1	0.79	0.88	0.51	1.61	0.64	0.69	1.02	2.44	0.32	2.01	0.92	2.09	13.92
1952	2	0.66	0.56	1.16	0.80	1.10	1.24	0.54	2.77	0.33	0.31	0.63	0.80	10.90
1953	3	1.12	0.67	1.44	1.44	1.42	0.56	2.06	1.32	0.31	1.00	1.10	0.68	13.12
1954	4	1.08	0.47	1.75	0.69	0.88	0.52	0.81	1.11	2.33	0.85	0.88	0.82	12.19
1955	5	0.89	1.16	0.57	1.18	1.28	1.09	0.40	1.89	0.63	0.63	1.21	0.53	11.46
1956	6	1.32	1.35	0.47	1.00	0.70	0.36	1.42	0.94	0.31	1.31	0.80	1.26	11.24
1957	7	0.97	0.71	1.49	1.29	1.61	1.36	1.29	3.04	0.31	1.84	1.48	0.82	16.21
1958	8	0.53	1.28	1.51	1.00	0.60	0.33	0.64	0.40	1.40	0.35	1.08	0.77	9.89
1959	9	0.61	1.49	0.93	0.83	0.52	1.11	0.75	1.34	1.60	0.95	0.37	0.75	11.25
1960	10	0.53	1.20	1.24	0.81	1.52	0.96	0.52	0.71	0.98	0.91	1.00	0.65	11.03
1961	11	0.35	0.69	1.41	1.37	1.82	0.62	0.63	1.26	3.86	1.16	0.88	0.70	14.75
1962	12	0.75	2.38	0.51	1.40	0.70	0.62	0.39	0.43	0.99	0.48	0.81	0.83	10.29
1963	13	0.44	0.45	0.62	1.10	0.41	0.87	0.80	2.21	0.73	0.59	0.86	0.59	9.67
1964	14	0.64	0.62	1.08	1.81	1.46	1.23	0.92	1.70	0.67	0.33	1.33	1.34	13.13
1965	15	0.82	0.93	0.87	0.98	2.26	1.63	1.62	0.71	1.57	0.65	1.11	1.32	14.47
1966	16	0.59	0.74	0.85	0.41	1.44	0.43	0.79	0.75	0.75	0.62	0.57	1.51	9.45
1967	17	0.80	0.64	0.58	1.14	1.49	2.33	0.98	1.21	1.54	0.77	0.61	1.82	13.91
1968	18	0.63	0.97	0.54	2.54	1.19	0.53	1.20	2.47	0.57	0.98	0.66	0.65	12.93
1969	19	1.16	0.60	0.67	1.78	0.57	2.69	1.32	1.65	1.46	1.98	1.03	0.63	15.54
1970	20	0.65	0.44	0.83	1.26	0.49	1.86	0.98	1.18	1.03	1.67	1.46	0.67	12.52
1971	21	0.77	0.79	0.98	0.96	1.36	0.36	0.47	0.85	1.23	1.97	0.98	1.00	11.72
1972	22	0.59	0.59	0.52	1.28	1.26	0.96	0.92	0.71	1.08	2.38	1.07	1.86	13.22
1973	23	0.90	0.33	1.14	1.45	1.19	1.21	1.67	1.31	1.38	0.68	1.61	1.13	14.00
1974	24	1.13	0.41	1.36	1.86	0.35	1.24	1.24	0.57	0.53	0.75	0.53	0.87	10.84
1975	25	0.85	0.65	1.13	1.37	1.87	1.49	2.32	0.55	0.79	1.35	0.81	0.83	14.01
1976	26	0.63	0.81	1.42	1.12	1.63	1.38	1.04	1.51	1.12	0.67	0.38	0.38	12.09
1977	27	0.49	0.61	0.95	0.90	0.79	0.51	1.11	1.83	0.92	1.13	1.15	0.78	11.17
1978	28	1.09	0.78	1.66	1.77	1.25	0.50	0.82	0.64	0.97	0.45	1.44	1.30	12.67
1979	29	0.94	0.72	1.95	1.00	2.01	0.53	0.50	1.18	0.48	1.36	1.42	0.57	12.66
1980	30	1.08	1.39	1.70	0.75	2.17	0.33	1.24	1.53	0.85	1.12	0.77	0.53	13.46
Mean[2)]		0.79	0.84	1.06	1.23	1.20	0.98	1.01	1.34	1.03	1.04	0.97	0.95	12.46
Std Dev[2)]		0.25	0.42	0.43	0.44	0.54	0.6	0.47	0.71	0.72	0.56	0.33	0.43	1.72

1) Based on correlation of 81 months of concurrent on-site and Little Hills Weather Station data.

2) 30-year period.

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TABLE 3

ESTIMATED AVERAGE AIR TERPERATURE AT RETORTED SHALE PILE[1)]

Calendar Sequence		Monthly Average Air Temperature (°F)												
Year	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1951	1	23.6	33.4	35.6	45.6	54.7	59.3	69.8	66.9	58.0	46.7	31.4	25.3	45.9
1952	2	21.2	23.4	29.4	46.5	54.4	63.8	68.2	66.5	60.6	49.3	29.7	25.8	44.9
1953	3	34.1	26.9	38.8	42.7	50.8	63.6	71.6	66.5	59.5	48.0	39.8	25.6	47.4
1954	4	31.6	35.4	35.8	49.4	55.7	62.5	72.3	66.7	60.7	50.8	39.3	25.4	48.8
1955	5	22.9	21.6	33.5	42.0	52.4	59.3	68.8	68.6	59.0	45.9	34.3	33.7	45.2
1956	6	34.5	22.6	35.5	44.6	53.7	66.1	68.4	64.6	60.2	47.6	28.8	21.9	45.7
1957	7	25.2	29.2	35.8	44.5	53.7	63.0	69.5	67.1	57.7	49.9	33.2	29.6	46.5
1958	8	25.5	36.5	35.6	42.9	55.6	62.8	65.9	68.0	57.7	45.7	33.0	32.2	46.8
1959	9	26.0	29.5	35.1	44.7	53.4	66.0	69.5	67.7	58.5	47.2	37.2	29.1	47.0
1960	10	23.3	22.2	38.2	47.8	54.0	64.0	69.6	68.3	63.2	49.3	39.5	26.4	47.2
1961	11	25.7	33.9	39.0	44.8	55.8	65.9	70.8	70.6	54.7	47.5	34.3	26.0	47.5
1962	12	20.0	33.6	31.4	49.4	54.8	62.8	68.3	66.6	60.3	51.1	41.1	28.0	47.3
1963	13	18.4	36.4	36.3	45.4	56.8	61.8	70.1	68.6	61.7	53.8	39.6	25.1	47.9
1964	14	21.4	21.6	29.6	44.1	54.8	61.7	71.9	65.7	58.9	50.9	34.1	30.4	45.5
1965	15	29.7	27.9	30.4	45.8	53.6	60.5	68.4	65.4	58.7	47.9	41.1	27.9	46.4
1966	16	23.7	24.0	37.4	43.0	54.6	61.5	71.0	66.5	58.8	45.8	40.9	22.7	45.9
1967	17	25.4	31.1	43.3	46.6	53.3	60.8	70.7	69.5	61.5	50.3	39.2	20.2	47.7
1968	18	19.9	30.5	38.1	39.6	51.1	61.7	67.8	63.2	55.2	47.6	34.3	24.0	44.4
1969	19	30.3	28.0	31.3	48.5	57.8	60.5	71.2	71.3	61.5	42.1	34.0	29.2	47.2
1970	20	28.2	35.9	34.4	41.1	54.8	61.8	69.7	70.6	56.7	42.0	38.4	29.3	46.9
1971	21	29.0	28.3	35.5	44.6	52.0	62.5	70.6	70.0	53.3	46.0	33.7	23.8	45.8
1972	22	28.1	33.3	42.7	47.1	53.5	64.8	69.0	66.7	59.0	50.3	32.6	19.6	47.2
1973	23	16.7	23.1	34.9	41.7	52.8	61.3	67.5	69.2	57.2	48.9	35.5	25.9	44.6
1974	24	25.2	24.5	40.9	43.8	56.0	64.7	69.8	65.4	57.1	49.0	36.8	22.4	46.3
1975	25	23.9	28.7	35.8	40.7	50.5	59.4	69.7	64.9	57.1	47.1	33.6	28.9	45.0
1976	26	23.7	33.6	32.7	45.9	55.7	62.1	70.3	66.1	59.7	44.8	34.9	26.9	46.4
1977	27	25.6	32.0	34.5	48.2	53.7	67.5	70.8	68.5	60.5	48.8	37.7	33.9	48.5
1978	28	30.3	32.7	41.0	47.0	52.6	62.4	68.7	65.3	56.9	47.6	33.4	18.2	46.4
1979	29	17.1	28.2	36.4	43.8	53.1	61.8	67.3	65.4	60.7	49.0	28.3	25.3	44.7
1980	30	28.3	32.8	35.7	41.1	52.1	62.5	70.4	65.1	56.9	45.4	33.4	34.7	46.5
Mean[2)]		25.3	29.4	35.8	44.8	53.9	62.6	69.6	67.2	58.7	47.9	35.4	26.6	46.4
Std Dev[2)]		4.58	4.77	3.52	2.62	1.74	2.06	1.47	2.00	2.23	2.56	3.62	4.12	1.14

1) Based on correlation of 48 months of concurrent on-site and Little Hills Weather Station data.

2) 30-year period.

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TABLE 4

ESTIMATED AVERAGE WIND SPEED AT RETORTED SHALE PILE[1)]

Calendar Sequence		Monthly Average Wind Speed (MPH)												
Year	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1951	1	5.1	5.4	5.8	5.8	5.8	5.8	5.7	5.7	5.6	5.4	5.3	5.0	5.5
1952	2	5.0	5.4	5.7	5.6	5.7	5.9	5.6	5.5	5.6	5.2	5.1	4.9	5.4
1953	3	5.0	5.5	5.7	5.8	6.0	6.0	5.8	5.5	5.6	5.5	5.3	5.2	5.6
1954	4	5.0	5.4	5.6	5.8	5.8	6.0	5.8	5.7	5.7	5.3	5.2	5.0	5.5
1955	5	5.1	5.3	5.6	6.1	6.0	5.8	6.0	5.4	5.6	5.3	5.3	5.3	5.6
1956	6	5.2	5.6	5.7	5.8	5.9	6.1	5.6	5.7	5.6	5.6	5.3	5.3	5.6
1957	7	5.1	5.0	5.6	5.7	5.6	5.4	5.6	5.4	5.3	5.2	5.1	4.9	5.3
1958	8	5.0	5.2	5.4	5.6	5.6	6.0	5.8	5.6	5.4	5.2	5.1	5.0	5.4
1959	9	5.0	5.5	5.6	5.6	5.7	5.6	5.4	5.4	5.3	5.0	5.0	5.0	5.3
1960	10	4.9	5.1	5.3	5.5	5.4	5.5	5.5	5.4	5.3	5.0	5.0	4.9	5.2
1961	11	5.3	5.6	5.8	6.1	6.1	6.2	6.0	5.9	5.9	5.7	5.5	5.3	5.8
1962	12	5.6	5.9	5.8	6.0	6.4	6.1	6.0	6.0	5.8	5.7	5.3	5.1	5.8
1963	13	5.1	5.4	5.8	6.3	6.2	6.3	6.0	5.7	5.6	5.7	5.6	5.3	5.8
1964	14	5.5	5.8	5.9	6.4	6.6	6.7	6.8	6.4	6.5	6.0	5.9	5.6	6.2
1965	15	5.6	5.8	6.1	6.4	6.6	6.5	6.3	6.2	6.4	5.8	5.8	5.3	6.1
1966	16	5.2	5.6	5.9	5.9	6.3	6.8	6.5	6.6	6.6	6.3	5.6	5.6	6.1
1967	17	5.4	5.9	6.4	7.0	6.1	6.5	6.3	6.6	6.5	6.4	6.0	5.9	6.2
1968	18	5.8	5.7	6.4	6.8	6.8	6.5	6.4	6.9	6.9	6.5	6.4	6.1	6.4
1969	19	6.3	6.7	6.7	7.1	7.0	6.9	6.9	6.6	6.8	6.4	6.4	6.1	6.7
1970	20	6.0	6.4	6.6	7.1	7.1	7.1	6.9	6.8	7.0	6.4	6.2	6.3	6.7
Mean[2)]		5.3	5.6	5.9	6.1	6.1	6.2	6.1	6.0	6.0	5.7	5.5	5.4	5.8
Std Dev[2)]		0.38	0.41	0.38	0.52	0.48	0.47	0.47	0.52	0.58	0.50	0.45	0.44	0.46

1) Based on correlation of concurrent monthly on-site and Grand Junction Airport data.

2) 20-year period.

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TABLE 5

ESTIMATED AVERAGE RELATIVE HUMIDITY AT RETORTED SHALE PILE[1)]

Calendar Sequence Year	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1951	1	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1952	2	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1953	3	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1954	4	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1955	5	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1956	6	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1957	7	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1958	8	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1959	9	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1960	10	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1961	11	0.64	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54[3)]
1962	12	0.63	0.63	0.54	0.49	0.47	0.44	0.46	0.44	0.48	0.52	0.57	0.61	0.52
1963	13	0.65	0.57	0.54	0.47	0.43	0.45	0.46	0.55	0.51	0.53	0.57	0.57	0.53
1964	14	0.59	0.52	0.54	0.54	0.48	0.45	0.45	0.51	0.51	0.45	0.60	0.63	0.52
1965	15	0.64	0.63	0.56	0.54	0.51	0.50	0.52	0.50	0.55	0.54	0.58	0.65	0.56
1966	16	0.63	0.62	0.51	0.49	0.48	0.47	0.48	0.45	0.51	0.52	0.60	0.66	0.54
1967	17	0.54	0.48	0.48	0.44	0.50	0.53	0.52	0.50	0.51	0.49	0.55	0.68	0.52
1968	18	0.67	0.65	0.53	0.55	0.51	0.45	0.49	0.55	0.48	0.54	0.59	0.63	0.55
1969	19	0.67	0.62	0.56	0.50	0.48	0.52	0.49	0.50	0.52	0.59	0.56	0.62	0.55
1970	20	0.60	0.52	0.57	0.52	0.45	0.48	0.48	0.49	0.49	0.55	0.57	0.60	0.53
Mean[2)]		0.63	0.59	0.54	0.51	0.49	0.47	0.48	0.50	0.50	0.53	0.58	0.62	0.54
Std Dev[2)]		0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.03	0.01	0.02	0.01

1) Based on correlation of concurrent monthly on-site and Grand Junction Airport data.

2) 20-year period.

3) No data, used mean value for 1962 through 1978 calendar years.

Woodward-Clyde Consultants

TABLE 6

RELATIONSHIPS USED TO ESTIMATE MONTHLY LONG-TERM CLIMATIC DATA AT THE RETORTED SHALE DISPOSAL SITE

Variable	Relationship	R^2	Standard Error of Estimate[1)]
Precipitation[2)] (Inches)	Y = 0.3117 + 0.6705X	0.54	0.52
Average Air Temperature[3)] (°F)	Y = 3.624 + 1.001X	0.98	2.3
Wind Speed[4)] (MPH)	Y = 4.277 + 0.2538X	0.24	0.56
Relative Humidity[5)] (Decimal)	Y = 0.3503 + 0.4151X	0.50	0.06

1) Standard error of estimate has units of the variable under consideration.

2) X = Monthly precipitation at Little Hills,
Y = Monthly precipitation at site.

3) X = Average monthly air temperature at Little Hills,
Y = Average monthly air temperature at site.

4) X = Average monthly wind speed at Grand Junction Airport,
Y = Average monthly wind speed at site.

5) X = Average monthly relative humidity at Grand Junction Airport,
Y = Average monthly relative humidity at site.

TABLE 7

RUNOFF FROM UNION PROCESS B RETORTED SHALE FOR UOC TEST PLOTS UNDER SELECTED TREATMENT CONDITIONS[1)]

25% Slope - West Aspect

Calendar Year	Runoff (inches) for Treatment		
	Process B Shale	15 cm Soil	30 cm Soil
1976	3.4	3.0	3.3
1977	0.04	0.04	0.04
1978	2.8	2.5	3.0
1979	1.1	1.0	1.0
1980	2.8	2.8	1.7
Mean	2.03	1.87	1.81

50% Slope - North Aspect

Calendar Year	Runoff (inches) for Treatment		
	Process B Shale	15 cm Soil	B Chemical Mulch
1976	2.6	1.6[2)]	3.0
1977	0.12	0.12	0.08
1978	2.2	1.1	2.8
1979	0.47	0.35	0.83
1980	2.6	1.9	2.8
Mean	1.60	1.01	1.90

1) Based on data from Berg and others, 1978; 1979; Berg and Harbert, 1978; and Kilkelly, 1981. These data are for UOC test plots at an approximate elevation of 5800 feet.

2) Possibly affected by a leak in the runoff sump.

TABLE 8

COMPARISON OF ANNUAL PRECIPITATION VERSUS EVAPOTRANSPIRATION
AND FREE WATER SURFACE EVAPORATION
AT THE RETORTED SHALE PILE

Sequence Year	Precipitation[1] (inches)	Evapotranspiration[2] (inches)	Free Water Surface Evaporation[3] (inches)
1	13.92	20.10	35.94
2	10.90	21.23	35.87
3	13.12	20.11	37.55
4	12.19	22.35	39.40
5	11.46	19.34	35.41
6	11.24	20.73	36.51
7	16.21	20.59	36.16
8	9.89	19.92	36.10
9	11.25	20.82	36.89
10	11.03	22.06	37.71
11	14.75	21.22	39.04
12	10.29	21.81	40.15
13	9.67	22.36	40.25
14	13.13	20.94	39.30
15	14.47	20.04	35.47
16	9.45	20.09	38.75
17	13.91	21.46	40.64
18	12.93	18.23	35.00
19	15.54	21.80	39.89
20	12.52	19.53	40.36
21	11.72	19.65	5)
22	13.22	21.31	5)
23	14.00	19.68	5)
24	10.84	20.80	5)
25	14.01	18.49	5)
26	12.09	20.66	5)
27	11.17	22.26	5)
28	12.67	20.05	5)
29	12.66	20.14	5)
30	13.46	19.07	5)
Mean	12.46[4]	20.56[4]	37.82[6]
Std. Dev.	1.72[4]	1.10[4]	1.95[6]

1) From Table 2.
2) Blaney-Criddle method (rainfall not limiting) (SCS, 1972).
3) Meyer (1915) equation, period limited by availability of data at Grand Junction.
4) 30-year simulation period.
5) No estimate made.
6) 20-year simulation period.

TABLE 9

SUMMARY OF DURING-CONSTRUCTION WATER BALANCE
FOR FLAT AREAS OF PROPOSED RETORTED SHALE DISPOSAL PILE

Sequence Year	Precipitation[1] (inches)	Evaporation[2] (inches)	Runoff[3] (inches)	Water Into Pile[4] (inches)
1	13.92	10.68	0	3.24
2	10.90	10.49	0	0.41
3	13.12	11.26	0	1.86
4	12.19	10.74	0	1.45
5	11.46	10.40	0	1.06
6	11.24	9.20	0	2.04
7	16.21	12.82	0	3.39
8	9.89	8.47	0	1.42
9	11.25	10.75	0	0.50
10	11.03	10.12	0	0.91
11	14.75	11.09	0	3.66
12	10.29	8.60	0	1.69
13	9.67	9.67	0	0.0
14	13.13	10.79	0	2.34
15	14.47	12.23	0	2.24
16	9.45	8.95	0	0.50
17	13.91	12.96	0	0.95
18	12.93	11.42	0	1.51
19	15.54	13.37	0	2.17
20	12.52	11.44	0	1.08
Total[5]	247.87	215.45	0	32.42
Mean[5]	12.39	10.77	0.0	1.62

1) Precipitation falls as rain (no storage of snow is assumed, that is, any snow falling on the surface is assumed to melt rather than accumulate during the winter) (Table 2).
2) Estimated evaporation from pile surface only.
3) Estimated based on a curve number = 10 (0.0 inch per year runoff).
4) Precipitation less evaporation and runoff.
5) 20-year simulation period.

TABLE 10

WATER ENTERING RETORTED SHALE DISPOSAL PILE
DURING CONSTRUCTION

Sequence Year[1)]	Unreclaimed Surface Area (acres)	Water Volume (acre-feet)	Sequence Year[1)]	Unreclaimed Surface Area (acres)	Water Volume (acre-feet)
1	38	10	25	142	13
2	46	2	26	140	24
3	54	8	27	138	39
4	62	7	28	136	16
5	70	6	29	134	6
6	61	10	30	132	10
7	52	15	31	143	44
8	43	5	32	147	21
9	34	1	33	151	0
10	25	2	34	155	30
11	16	5	35	159	30
12	7	1	36	163	7
13	19	0	37	167	13
14	38	7	38	171	22
15	57	11	39	175	32
16	76	3	40	179	16
17	95	8	41	146	39
18	114	14	42	116	4
19	133	24	43	86	13
20	152	14	44	56	7
21	150	41	45	26	2
22	148	5	46	0	0
23	146	23			
24	144	17			

ESTIMATED TOTAL DURING-CONSTRUCTION WATER ENTERING PILE (45-year period) 627

1) Using 20-year simulation period sequentially 2 times and adding first 5 years.

TABLE 11

SUMMARY OF WATER BALANCE DURING SUPPLEMENTAL IRRIGATION OF RETORTED SHALE DISPOSAL PILE

Sequence Year	Precipitation Plus Irrigation[1] (inches)	Evapotranspiration[2] (inches)	Runoff[3] (inches)	Change In Soil Moisture Storage[4] (inches)	Water Into Pile[5] (inches)
1	21.92	20.10	0.60	1.22	0.0
2	18.89	21.23	0.70	-3.04	0.0
3	21.11	20.11	0.58	0.42	0.0
4	20.20	21.36	0.50	-1.66	0.0
5	19.46	19.28	0.48	-0.30	0.0
6	19.24	19.26	0.16	-0.18	0.0
7	24.20	20.59	1.09	2.52	0.0
8	17.88	19.16	0.17	-1.45	0.0
9	19.24	20.51	0.38	-1.65	0.0
10	19.04	18.76	0.31	-0.03	0.0
11	23.15	21.22	1.45	0.48	0.0
12	18.29	18.83	0.25	-0.79	0.0
13	17.66	17.45	0.40	-0.19	0.0
14	21.13	19.30	0.61	1.22	0.0
15	22.46	20.04	0.96	1.46	0.0
16	17.46	19.16	0.25	-1.96	0.0
17	21.91	20.82	0.85	0.24	0.0
18	20.92	18.22	0.88	1.82	0.0
19	23.52	21.80	1.02	0.70	0.0
20	20.53	19.54	0.47	0.52	0.0
21	19.72	19.52	0.25	-0.22	0.17
22	21.20	21.01	0.38	-0.19	0.0
23	22.00	19.67	0.65	1.68	0.0
24	18.85	19.68	0.35	-3.33	2.15
25	22.02	18.50	0.90	2.62	0.0
26	20.09	20.66	0.62	-1.19	0.0
27	19.18	20.94	0.32	-2.09	0.01
28	20.66	19.13	0.35	1.18	0.0
29	20.66	20.14	0.43	0.09	0.0
30	21.46	19.07	0.64	1.75	0.0
Total[6]	614.05	595.06	17.00	-0.35	2.33
Mean[6]	20.47	19.84	0.57	-0.01	0.08

1) Precipitation plus April through September irrigation application of 8 inches.

2) Blaney-Criddle Method (SCS, 1972).

3) Estimated based on CN = 54.

4) Upper 6 feet of pile.

5) Water lost below root zone (upper 6 feet of pile).

6) 30-year simulation period.

TABLE 12

WATER ENTERING RETORTED SHALE DISPOSAL PILE
DURING SUPPLEMENTAL IRRIGATION

Sequence Year [1]	Area Under Irrigation [2] (acres)	Water Volume (acre-feet)	Sequence Year [1]	Area Under Irrigation [2] (acres)	Water Volume (acre-feet)
1	0	0	26	22	0
2	30	0	27	22	.02
3	30	0	28	22	0
4	30	0	29	22	0
5	30	0	30	22	0
6	34	0	31	18	0
7	34	0	31	18	0
8	34	0	33	18	0
9	34	0	34	18	0
10	34	0	35	18	0
11	34	0	36	18	0
12	34	0	37	18	0
13	20	0	38	18	0
14	20	0	39	18	0
15	20	0	40	18	0
16	20	0	41	30	0
17	20	0	42	30	0
18	20	0	43	30	0
19	20	0	44	30	0
20	20	0	45	30	0
21	22	.30	46	30	0
22	22	0			
23	22	0			
24	22	3.94			
25	22	0			
Estimated total irrigation water entering pile (46-year period)					4.26

1) Using 30-year simulation period sequentially 1 time adding first 18 years.

2) Based on areas available for each successive year for 1 year of irrigation.

TABLE 13

SUMMARY OF DURING-CONSTRUCTION AND SUPPLEMENTAL IRRIGATION WATER ADDITIONS TO THE RETORTED SHALE DISPOSAL PILE[1)]

Water Source	Water Added To Pile (ac-ft)	Cumulative Water In (ac-ft)	Average Pile Moisture As A Percent by Volume (%)
Initial Moisture (from cooling)	17,687	17,687	17.5[2)]
Precipitation During Construction	627	18,314	18.1
Supplemental Irrigation	4	18,318	18.1

1) Retorted shale pile volume = 101,070 acre-feet

(171,700,000 tons at an average unit weight of 78 lb/ft^3)

2) From Stearns-Roger Engineering Corporation (1983) Letter to Cathedral Bluffs Shale Oil Company.

TABLE 14

SUMMARY OF POST-RECLAMATION WATER BALANCE FOR PROPOSED RETORTED SHALE DISPOSAL PILE

Sequence Year[1]	Precipitation (inches)	Evapotranspiration (inches)	Runoff[2] (inches)	Change in Soil Moisture Storage[3] (inches)	Seepage Below 6 Feet (inches)
1	13.92	15.17	0.08	-1.33	0.0
2	10.90	13.20	0.12	-2.42	0.0
3	13.12	12.76	0.01	0.35	0.0
4	12.19	12.23	0.05	-0.09	0.0
5	11.46	11.41	0.01	0.04	0.0
6	11.24	10.92	0.00	0.32	0.0
7	16.21	15.70	0.18	0.33	0.0
8	9.89	10.44	0.00	-0.55	0.0
9	11.25	11.98	0.00	-0.73	0.0
10	11.03	10.50	0.00	0.53	0.0
11	14.75	13.93	0.43	0.39	0.0
12	10.29	10.63	0.05	-0.39	0.0
13	9.67	9.83	0.02	-0.19	0.0
14	13.13	11.90	0.01	1.22	0.0
15	14.47	14.68	0.04	-0.25	0.0
16	9.45	9.80	0.00	-0.35	0.0
17	13.91	13.51	0.05	0.35	0.0
18	12.93	13.91	0.14	-1.12	0.0
19	15.54	14.22	0.11	1.21	0.0
20	12.52	12.34	0.00	0.18	0.0
21	11.72	11.88	0.01	-0.17	0.0
22	13.22	12.22	0.05	0.95	0.0
23	14.00	14.74	0.00	-0.74	0.0
24	10.84	12.18	0.00	-1.34	0.0
25	14.01	13.73	0.05	0.23	0.0
26	12.09	12.97	0.00	-0.88	0.0
27	11.17	10.00	0.00	1.17	0.0
28	12.67	11.86	0.00	0.81	0.0
29	12.66	13.39	0.01	-0.74	0.0
30	13.46	14.12	0.02	-0.68	0.0
Total (30-year)[4]	373.71	376.15	1.44	-3.89	0.0
Mean[4]	12.46	12.54	0.05	-0.13	0.0

1) Represents period from January 1951 through December 1980
2) Runoff curve number = 54
3) In upper 6 feet of pile
4) 30-year simulation period

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TABLE 15

ASSUMED LIMITING VELOCITIES FOR OPEN CHANNELS
(STRAIGHT AFTER AGING)

Material	For Clear Water Velocity (ft/s)	Water Transporting Colloidal Size Velocity (ft/s)
Fine sand noncolloidal	1.50	2.50
Sandy loam noncolloidal	1.75	2.50
Silt loam noncolloidal	2.00	3.00
Alluvial silts noncolloidal	2.00	3.50
Ordinary firm loam	2.50	3.50
Stiff clay, very colloidal	3.75	5.00
Alluvial silts colloidal	3.75	5.00
Shales and hardpans	6.00	6.00
Fine gravel	2.50	5.00
Graded loam to cobbles when noncolloidal	3.75	5.00
Graded silts to cobbles when colloidal	4.00	5.50
Coarse gravel noncolloidal	4.00	6.00
Cobbles and shingles	5.00	5.50

1) Source: Modified from Fortier and Scobey (1926).

TABLE 16

DESIGN STORMS AND GENERAL DETAILS OF DIVERSION AND COLLECTION CHANNELS

Channel Designation[1]	Design Storm	Drainage Area (acres)	Design Discharge (cfs)	Bottom Width[2] (ft)	Sideslopes[3] (H:V)	Approximate Channel Depth[4] (ft)
DC-1	100-yr, 24-hr	17.3	8.0	3	2:1	1.9
DC-2	100-yr, 24-hr	35.4	13.0	4	2:1	2.0
DC-3	PMP	870	4300.	15	1:1	22.[5]
DC-4	PMP	52.0	273	15	1:1	2.6[5]
DC-5	100-yr, 24-hr	241.	48	5	2:1	3.2
DC-6	100-yr, 24-hr	131.	32	5	2:1	2.6
DC-7[6]	100-yr, 24-hr	9.6	5.2	3	2:1	1.8
DC-8	100-yr, 24-hr	59.9	19	4	2:1	2.2
DC-9	100-yr, 24-hr	67.8	21	4	2:1	2.2
DC-10	100-yr, 24-hr	90.1	25	4	2:1	2.5
DC-11	100-yr, 24-hr	82.6	24	4	2:1	2.5
DC-12	100-yr, 24-hr	86.7	25	4	2:1	2.5
DC-13	100-yr, 24-hr	98.2	27	4	2:1	2.6
DC-14	100-yr, 24-hr	104	28	4	2:1	2.6
DC-15	100-yr, 24-hr	98.3	27	4	2:1	2.6
DC-16[6]	100-yr, 24-hr	5.3	3.3	3	2:1	1.6

1) See Figure 23 for locations.
2) Channel section assumed to be trapezoidal.
3) H:V = horizontal to vertical.
4) Includes freeboard.
5) No freeboard was added to the flow depth for the peak discharge resulting from the PMP storm.
6) This was initially sized as a collector channel for a retention pond and 100-year, 24-hour storm; however, it is also adequate as a collection channel for a detention pond and a 25-year, 24-hour storm.

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TABLE 17

GENERAL DETAILS OF RETENTION PONDS

Retention Pond Designation[1]	Drainage Area (acres)	Liner Advance Distance (ft)	Estimated Runoff Volume (acre-feet)	Estimated Sediment Volume (acre-feet)	Approximate Embankment Height (ft)
RP-1	41.7	500	2.4	0.3	11.8
		1000	3.3	0.4	12.9
RP-2	26.6	500	1.2	0.1	8.7
		1000	1.7	0.2	10.2
RP-3	41.6	500	2.6	0.6	16.0
		1000	3.3	0.8	19.3
RP-3A	35.5	500	1.5	0.2	10.6
		1000	2.0	0.4	13.1
RP-4	32.6	500	1.9	0.4	9.6
		1000	2.3	0.5	10.5
RP-5A	30.0	500	2.1	0.3	11.4
		1000	3.2	0.5	14.5
RP-5B	30.9	500	2.0	0.4	8.3
		1000	2.8	0.6	11.1
RP-5	45.2	500	2.7	0.3	8.5
		1000	4.7	0.5	10.7
RP-6A	68.0	500	6.1	0.7	15.3
		1000	7.1	0.8	16.9
RP-6 (DP-4)[2]	74.4	500	3.8	0.4	14.7
		1000	5.3	0.4	16.6
RP-7 (DP-5)[2]	39.1	500	2.1	0.2	12.0
		1000	3.5	0.4	13.8
RP-8	58.6	500	3.0	0.9	9.7
		1000	4.2	1.4	10.3
RP-9	81.7	500	4.8	1.5	15.1
		1000	6.5	2.1	18.6
RP-10	39.7	500	1.9	0.2	14.5
		1000	2.7	0.3	16.4
RP-11	72.3	500	5.8	0.6	17.1
		1000	7.2	0.8	21.1
RP-12	74.8	500	5.3	1.1	12.6
		1000	7.9	1.7	16.4
RP-13	80.4	500	6.0	2.0	17.6
		1000	8.4	2.8	20.9
RP-14	75.6	500	6.0	2.0	20.5
		1000	7.9	2.6	23.1
RP-15	71.3	500	5.7	1.9	13.7
		1000	7.5	2.5	17.0
RP-16	84.8	500	6.4	2.1	13.6
		1000	8.9	2.9	14.9
RP-17	81.0	500	5.3	1.7	18.3
		1000	7.0	2.4	21.9
RP-18	83.0	500	5.4	1.4	18.0
		1000	7.6	2.0	22.0
RP-19 (DP-14)[2]	44.7	500	2.6	0.8	21.1
		1000	2.8	0.9	20.7
RP-20 (DP-15)[2]	16.1	500	1.2	0.4	9.1
		1000	1.3	0.4	9.3

1) See Figure 23 for locations. All are designed for 100-year, 24-hour storm.
2) Later used as detention ponds (see Table 19).

TABLE 18

RETENTION POND TIME SEQUENCE

Retention Pond Designation[1]	Year On Line	Year Off Line	Approximate Life (yrs)
RP-1	1	2	1
RP-2	1	2	1
RP-3	2	4	2
RP-3A	2	4	2
RP-4	2	4	2
RP-5A	4	5	1
RP-5B	4	5	1
RP-5	4	6	2
RP-6A	6	7	1
RP-6 (DP-4)[3]	7	8	1
RP-7 (DP-5)[2][3]	7	8	1
RP-8	13	17	4
RP-9	13	17	4
RP-10	17	18	1
RP-11	17	18	1
RP-12	18	20	1
RP-13	20	23	3
RP-14	23	26	3
RP-15	26	29	3
RP-16	29	31	2
RP-17	31	36	5
RP-18	36	41	5
RP-19 (DP-14)[3]	41	43	2
RP-20 (DP-15)[3]	41	43	2

1) See Figure 23 for locations.

2) Dam would have to be temporarily reestablished when this corner of the disposal pile is tied to the advance from Sorghum Gulch.

3) Later used as detention ponds (see Table 19).

TABLE 12

DESCRIPTION OF TEST SEQUENCE

Description Code (DS-) [1]	Time On Line	Time Off Line	Acceptable Bit Level
DS-1	1	2	1
DS-2	1	2	1
DS-3	1	4	1
DS-3A	2	4	1
DS-4	2	4	1
DS-4A	4	8	1
DS-5A	4	8	1
DS-5	4	8	1
DS-6A	6	7	1
DS-6 (DS-4)[2][3]	7	8	1
DS-7 (DS-5)[2][3]	7	8	1
DS-8	12	12	1
DS-9	41	17	1
DS-10	17	16	1
DS-11	17	16	1
DS-12	18	20	1
DS-13	20	20	1
DS-14	21	26	1
DS-15	26	26	1
DS-16	26	31	1
DS-17	31	36	1
DS-18	36	41	1
DS-19 (DS-14)[3]	41	43	1
DS-20 (DS-15)[3]	41	43	1

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1) See Figure 22 for locations.

2) Time would have to be temporarily reestablished when this mirror or the diagonal pile is tied to the adverse Zone Doppler mode.

3) Later used as detection pulse (see Table 13).

TABLE 19

GENERAL DETAILS OF DETENTION PONDS

Detention Pond Designation[1]	Drainage Area (acres)	Runoff Volume (acre-feet)	Sediment Volume (acre-feet)	Spillway Discharge[2] (cfs)	Spillway Pipe Diameter (inches)	Approximate Embankment Height[3] (ft)
DP-1	35.4	0.8	0.1	13	24	6
DP-2	170.	3.9	0.5	38	36	16
DP-3	131.	3.0	0.4	32	36	14
DP-4 (RP-6)[4]	127.	2.9	0.4	30	36	14
DP-5 (RP-7)[4]	23.3	0.5	0.1	10	24	5
DP-6	59.9	1.4	0.2	19	30	9
DP-7	67.8	1.6	0.2	21	30	9
DP-8	90.1	2.1	0.3	25	36	11
DP-9	82.6	1.9	0.2	24	36	11
DP-10	86.7	2.0	0.3	25	36	11
DP-11	98.2	2.3	0.3	27	36	12
DP-12	104.	2.4	0.3	28	36	13
DP-13	98.3	2.3	0.3	27	36	12
DP-14 (RP-19)[4]	121.	2.8	0.4	30	36	14
DP-15 (RP-20)[4]	16.1	0.4	0.1	7.3	24	4

1) See Figure 23 for locations. All are designed to store runoff from 25-year, 24-hour storm.

2) Spillway sized to pass peak discharge resulting from a 100-year, 24-hour storm.

3) Includes 1 foot of freeboard.

4) Used previously as retention pond (see Table 17).

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TABLE 20

DETENTION POND TIME SCHEDULE

Detention Pond Designation[1]	Year On Line	Year Off Line	Expected Life (yrs)
DP-1	1	5	4
DP-2	2	9	7
DP-3	7	15	8
DP-4 (RP-6)[2]	10	15	5
DP-5 (RP-7)[2]	10	15	5
DP-6	13	18	5
DP-7	15	20	5
DP-8	18	24	6
DP-9	22	28	6
DP-10	24	30	6
DP-11	26	33	7
DP-12	29	36	7
DP-13	31	38	7
DP-14 (RP-19)[2]	41	47	8
DP-15 (RP-20)[2]	41	47	8

1) See Figure 21 for locations.

2) Used previously as retention ponds (see Table 17).

TABLE 21

TOPSOIL STRIPPING DEPTHS, VOLUMES, AND LIMITING CHARACTERISTICS

Map Unit Symbol and Name	Area of Map Unit (acres)	Area of Named Soil (acres)	Area of Named Soil (percent)[1]	Depth of Suitable Topsoil (feet)	Volume of Suitable Topsoil[2] (acre-feet)	Limiting Soil Characteristics
33 Forelle loam, 3 to 8% slopes	83.4	70.9	85	5.0	354.5	
64 Piceance fine sandy loam, 5 to 15% slopes	92.8	78.9	85	2.5	197.3	
70 Redcreek-Rentsac complex, 5 to 30% slopes	553.1					
Redcreek		331.9	60	1.3	431.5	
Rentsac		165.9	30	0.5	83.0	High coarse fragment content below 0.5 ft.
73 Rentsac channery loam, 5 to 50% slopes	365.7	292.6	80	0.5	146.3	High coarse fragment content below 0.5 ft.
TOTAL	1095				1212.6	

[1]Inclusions of dissimilar soils constitute the remainder of the map unit.

[2]Topsoil volume from inclusions of dissimilar soils ranges from 0 to 790 acre-feet; additional volume expected to be about 440 acre-feet, for a total topsoil volume of 1653 acre-feet.

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TABLE 22

ESTIMATED RETORTED SHALE DISPOSAL PILE SURFACE AREA
AVAILABLE FOR RECLAMATION DURING PLACEMENT ACTIVITIES
AND ESTIMATED SUPPLEMENTAL WATER NEEDS

Year	Estimated Available Reclamation Area (Acres)		Estimated Supplemental Water Needs (Acre-Feet)	
	Incremental	Cumulative	Incremental	Cumulative
5	119	119	77	77
12	241	360	161	238
20	159	519	104	342
30	216	735	150	494
40	183	918	120	612
45	177	1095	100	712
46	0	1095	20	732

Notes:

1. The estimated supplemental water needs assume: (1) to stimulate plant growth an average of 8.0 inches of moisture per acre in excess of average yearly effective moisture available from precipitation would be added to reclaimed areas for a period of 1 year after they were seeded; (2) the moisture is added with sprinklers that operate at 65 percent efficiency; (3) the yearly acreage available for reclamation is evenly distributed between the milestones shown above; and (4) the moisture is applied for 6 months.

2. See Figure 22.

3. Incremental areas and water needs represent accumulations for a period; for example, 241 acres at 12 years represents approximately 34.4 acres per year from year 6 through 12 or 241 divided by 7.

TABLE 23

SUGGESTED SPECIES LIST FOR C-b TRACT RECLAMATION

	Species	
Grasses:	*Agropyron cristatum	- crested wheatgrass
	*A. elongatum	- tall wheatgrass
	*A. spicatum var. inerme	- beardless bluebunch wheatgrass
	*A. smithii(rosana)	- western wheatgrass
	*A. intermedium(amur)	- intermediate wheatgrass
	*Bromus marginatus	- mountain brome
	*Elymus cinerus	- Great Basin wildrye
	*E. junceas	- Russian wildrye
	*Festuca ovina	- hard sheep fescue
	*Oryzopsis lymenoides	- Indian ricegrass
Forbs:	*Hedysarum boreale (Utah)	- Utah sweetvetch
	*Medicago staiva	- Alfalfa
	*Penstemon sp.	- penstemon
Shrubs:	+Amelanchier spp.	- serviceberry
	*+Artemisia tridentata	- big sagebrush
	*Atriplex canescens	- four wing salt brush
	*A. confertifolia	- shadscale
	*+Cercocarpus montanus	- mountainmahogany
	*Cowania mexicana	- stansberry cliffrose
	*Ceratoides lanata	- winterfat
	*+Purshia tridentata	- bitterbrush
	+Symphoricarpos oreophilus	- snowberry
Trees:	+Juniperus osteosperma	- Utah juniper
	+J. scopulorum	- Rocky Mountain juniper
	+Pinus edulis	- pinyon pine

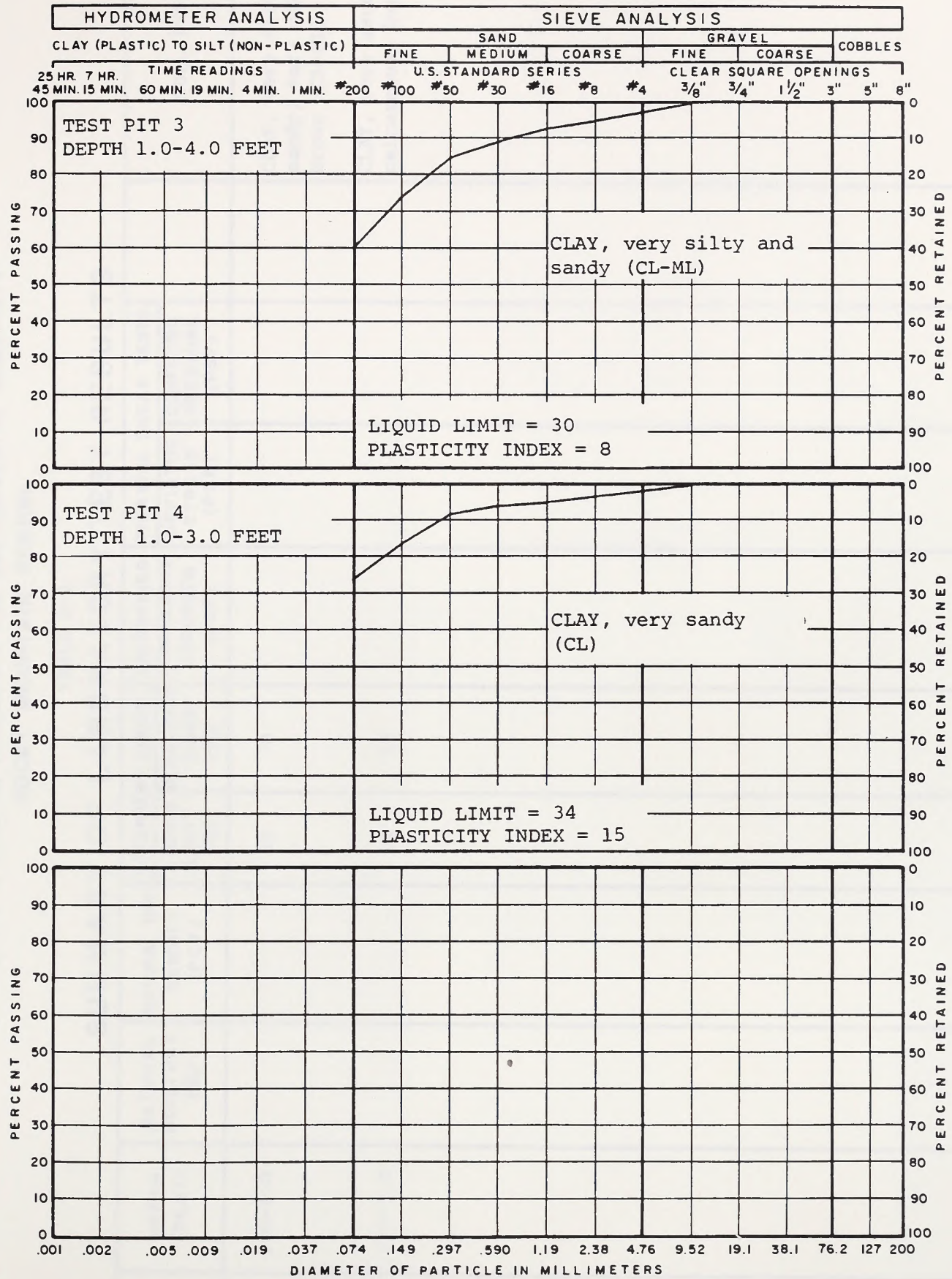
APPENDIX A

LABORATORY TEST RESULTS

WOODWARD - CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

ROCKY MOUNTAIN REGION



GRADATION ANALYSIS

JOB NO. 21120-19605

FIG. A-1

JOB NO. 21120-19605

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

ROCKY MOUNTAIN REGION

TABLE A-1

SUMMARY OF LABORATORY TEST RESULTS

PIT	DEPTH (FEET)	NATURAL MOISTURE (%)	NATURAL DRY DENSITY (PCF)	ATTERBERG LIMITS		UNCONFINED COMPRESSIVE STRENGTH (PSF)	TRIAXIAL SHEAR TESTS			SOIL TYPE
				LIQUID LIMIT (%)	PLASTICITY INDEX (%)		DEVIATOR STRESS (PSF)	CONFINING PRESSURE (PSF)		
3	1.0-4.0			30	8					CLAY, very silty and sandy, very calcareous, brown (CL-ML)
4	1.0-3.0			34	15					CLAY, very sandy, very calcareous, brown (CL)

Form 1279–3
(June 1984)

BORROWER'S

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Retorted shale di
Cathedral Bluffs

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